THIRTY-EIGHTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE

FOR AERONAUTICS

1952

INCLUDING TECHNICAL REPORTS
NOS. 1059 to 1110

CONTENTS.

TECHNICAL REPORTS

Letter of Transmittal

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, as amended, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-eighth Annual Report of the Committee covering the fiscal year 1952.

HARRY S. TRUMAN.

THE WHITE HOUSE,
    JANUARY 15, 1953.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 20, 1952.*

DEAR MR. PRESIDENT: In compliance with the act of Congress approved March 3, 1915, as amended (U. S. C. 1946, title 50, sec. 153), I have the honor to submit herewith the Thirty-eighth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1952.

Practical supersonic flight is only now beginning to materialize. It was hardly 5 years ago that man, in a special research airplane, first flew faster than sound in level controlled flight. During the past year, in Korea, American pilots have repeatedly flown faster than sound in dives. Supersonic tactical aircraft are now assured but their successful development requires much further research.

The Committee's report to the Congress notes that its operations have been reduced, although the need for increased aeronautical research is more urgent than at any time since V–J Day. Application of advances in aeronautical science provide the foundation for future air supremacy.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

THE PRESIDENT,
The White House, Washington, D. C.

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street.NW., Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President and serve as such without compensation.

THIRTY-EIGHTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 20, 1952.*

To the Congress of the United States:

In submitting to the Congress this thirty-eighth annual report of the National Advisory Committee for Aeronautics for the fiscal year 1952, the Committee feels an increasing sense of urgency from the realization that it has not been possible to utilize to their full capacity the extensive research facilities of the NACA at a time when an unfriendly power overseas has challenged our assumed air supremacy. The Congress has shown farsighted and timely understanding in supporting a continuing program to modernize and expand aeronautical research facilities, and the Committee takes considerable satisfaction in the value of the results obtained from these facilities. But the funds available for their operation are seriously inadequate for the welfare of the United States.

Since the achievement of supersonic flight in 1947 with a research airplane, our aircraft industry and the military services have been proceeding, in the face of extraordinarily difficult problems, to develop practical military airplanes to operate at supersonic speeds. These problems are increasingly acute in aerodynamics, propulsion, and structures. NACA research, which has a profound influence upon the future success of our military program, is decreasing while the need is increasing. Recent failures of high-speed airplanes in flight indicate that we do not fully understand all of the problems of high-speed flight. Innovations in design should be supported by more adequate research.

Since hostilities started in Korea, the Committee has submitted larger budget estimates to cover the needs of its research program, in the conviction that the United States cannot afford to risk its advanced position in scientific research in aeronautics, but only part of these needs have been met in the final appropriations. The

Committee may have failed to state clearly enough the necessity for more intensive research in view of the dangerous international situation.

In cooperation with the economy program of the Government, the Committee has endeavored to stretch the operating funds available to meet increasing research needs during the national build-up of air power. The Committee has had the assistance of leaders in science, industry, and the military services in selecting the most pressing research problems to receive attention. After making such selection, many important problems remain that require solution before further progress can be made in the quality and performance of high-speed aircraft, but attack on them must be deferred.

In the race for air supremacy, the date for the ultimate test is unknowable. The time available to carry out a logically planned research program is, consequently, a matter of judgment. What is left undone now may never be undertaken.

Nevertheless, there is one fundamental certainty: Our country is making an immense investment in security through air power. That investment will be only as sound as the adequacy of a continuing scientific research program without which there is a real danger that this air power might become second best. Research solves current problems but is most productive when it reveals new knowledge, leading to new applications. Research laboratories, consequently, must be used intensively and changed from time to time to deal with the new problems that come with progress.

Further modernization of the NACA research laboratories and, above all, adequate operating funds, are needed more urgently than at any time since V-J Day.

I am instructed by the Committee to bring this situation to the attention of the Congress.

Respectfully submitted.

. ·JEROME C. HUNSAKER, *Chairman.*

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Part I—TECHNICAL ACTIVITIES

THE NACA—WHAT IT IS AND HOW IT OPERATES

The business of the National Advisory Committee for Aeronautics is research, scientific laboratory research in aeronautics. The responsibilities of the NACA were received at the time of its establishment by the Congress in 1915, and are to "supervise and direct the scientific study of the problems of flight with a view to their practical solution" and also, to "direct and conduct research and experiment in aeronautics."

During the 37 years since its organization as an independent Federal agency, the NACA has sought to assess the current status of development of aircraft, both civil and military; to anticipate the research needs of aeronautics; to develop the scientific staff and novel research facilities required, and to acquire the needed information as rapidly as may be consistent with the national interest.

The Committee's research programs have had both the long-range, all-inclusive objective of acquiring the new scientific knowledge essential to assure American leadership in aeronautics, and the immediate objective of solving, as quickly as possible, the most pressing problems, thus to assure success of the Nation's aircraft construction program.

The 17 members of the Committee are appointed by and report to the President. They are assisted in the determination of research programs by five major and 23 subordinate committees, with a total membership of approximately 400 scientists from universities, engineers from the aircraft industry and the airlines, and experts from the civil and military agencies of the Government most concerned with aeronautics. These men are selected because of their technical ability, experience, and recognized leadership in a special field of competence, and serve in a personal and professional capacity without compensation. They provide material assistance in the consideration of problems related to their technological fields, review research in progress both at NACA laboratories and in other organizations, recommend research projects to be undertaken, and assist in the coordination of research programs. Membership in the technical committees and subcommittees, as well as the Industry Consulting Committee, is listed in part II of this report.

Research coordination is also accomplished through discussions by NACA technical personnel with the research staffs of the aviation industry, educational and scientific institutions, and other aeronautical agencies.

As a further aid, a West Coast representative maintains close liaison with the aeronautical research and engineering staffs of that geographical area.

Most of the research problems to be investigated are assigned to NACA's laboratories. Problems having to do with flight propulsion go to the newest of the three main facilities, the Lewis Flight Propulsion Laboratory at Cleveland. The Ames Aeronautical Laboratory, at Moffett Field, California, concentrates upon aerodynamic research, while at the Langley Aeronautical Laboratory, in Virginia, research is conducted on aerodynamic, structures, hydrodynamics, and other problems. Smaller NACA research installations are located at Wallops Island, off the Virginia Coast, where aerodynamic problems in the transonic and supersonic ranges are studied using rocket-propelled models in flight, and at Edwards Air Force Base, California, where specially-designed and specially-instrumented airplanes are used in the study of transonic and supersonic flight problems. The technical and administrative staff of the NACA totaled 7652 persons at the end of fiscal year 1952.

In addition to this major effort, the NACA sponsors and finances a coordinated program of research at a score of non-profit scientific and educational institutions, as well as at the National Bureau of Standards and the Forest Products Laboratory, thus to supplement the work carried on at NACA facilities. By this means, scientists and research engineers, whose skills and talents otherwise might not be available, contribute importantly to the Government's program of aeronautical problems. In addition, promising students assisting in these programs receive the scientific training which makes them useful additions to the country's scientific manpower.

Research proposals from such institutions are carefully screened to assure best use of the limited funds available to the NACA for sponsoring such activity. Similarly, results from these research projects are reviewed to maintain the quality of this part of the NACA program, and reports of the useful results are given the same wide distribution as other NACA publications.

During the fiscal year, most of the NACA technical subcommittees reviewed proposals for research projects, or gave attention to reports from completed contracts. Reports covering results of sponsored research totaled 92 during the year.

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During the fiscal year 1952 the following institutions participated in the contract research program:

National Bureau of Standards
Forest Products Laboratory
Armour Research Foundation
Battelle Memorial Institute
Polytechnic Institute of Brooklyn
California Institute of Technology
University of California
University of California at Los Angeles
Carnegie Institute of Technology
University of Chicago
University of Cincinnati
Clarkson College of Technology
Columbia University
Cornell University
University of Florida
Georgia Institute of Technology
Iowa State College
Johns Hopkins University
Massachusetts Institute of Technology
University of Michigan
University of Oklahoma
University of Pittsburgh
Purdue University
Rensselaer Polytechnic Institute of Technology
Stanford University
Syracuse University
Texas Agricultural and Mechanical College
University of Wisconsin

If the NACA's business is research, its "product" is research information. Research results, including those obtained in the Committee's laboratories and those derived elsewhere under NACA sponsorship, are distributed in the form of Committee publications. Reports and Technical Notes, containing information that is not classified for reasons of security, are available to the public in general. Translations of important foreign research information are issued as Technical Memorandums.

Current announcement of NACA publications is through the medium of the NACA Research Abstracts. In addition to covering NACA publications, this service includes important research reports received from abroad.

The NACA also prepares a large number of reports in which information of a classified nature is presented. These, for reasons of national security, are closely controlled as to circulation. When it is found possible to declassify such information, it may be published at a later date for wider distribution.

In addition to other means of transmitting quickly and efficiently research information, the NACA each year holds a number of technical conferences with representatives of the aviation industry, universities, and the military services. These are restricted meetings, because of the security classification of the material presented, and the subject material is usually about a specific field of interest. During the fiscal year 1952, four such technical conferences were held.

SOME EXAMPLES OF RESEARCH ACTIVITY

NEW ALTITUDE TEST FACILITIES AID IMPROVEMENTS OF TURBOJETS

During the summer of 1952 a new research tool was put into use at the NACA's Lewis Flight Propulsion Laboratory. What made the event of great importance was that it came at a time in the world race for air supremacy when bigger, more efficient powerplants are sorely needed for tomorrow's airplanes. Except for this new facility, the United States would not now have the research equipment so necessary for study, through their full range of power and altitude, of the largest turbojet engines now being developed.

Termed the Propulsion Systems Laboratory to distinguish it from other, smaller engine testing facilities at the Lewis Laboratory, the new equipment marks another milestone in a successful, 9-year effort by American research, first to catch up with the turbojet revolution, and then take the lead. Throughout this period, the NACA has continually increased the capacity of its altitude facilities to enable testing the more powerful engines under development.

Prior to World War II, although interest was shown in the United States in theoretical considerations of the possible adaptation of the long-known prinicple of jet reaction for use in aircraft, virtually all development effort in this country had been concentrated upon designing piston engines with more power and better fuel economy for the long-range fighters and bombers upon which American air defense plans were based.

In both Germany and Great Britain, the need for more powerful engines for short-range, high-performance interceptor aircraft made the idea of turbojet engines very attractive, despite the handicap of high fuel consumption. In 1941, even before American involvement in the war, Great Britain made available to the United States the Whittle engine. American production and improvement of this first British turbojet was assigned to the General Electric Co., while the nation's aircraft research and production establishments were kept at the more immediate task of providing the improved piston engines needed to win World War II.

Construction of the Lewis Laboratory was authorized in 1940, and provided facilities, superior to those of any nation, for propulsion research. Previously, neither the NACA nor the aircraft engine manufacturers had been able to do more than test complete engines under sea level conditions, except in actual flight, but

as the fighters and bombers of World War II continued to seek higher altitudes, it became imperative to perform extensive research on problems of high-altitude operation, to find solutions which could be applied quickly to current engines. Although some of this work could be done profitably in flight, the need was great for test equipment to enable study, under laboratory control with full instrumentation, of the operating characteristics of engines under conditions which simulated flight throughout the range of altitude and speed desired.

Fortunately, these test facilities at the Lewis Laboratory, although designed specifically for piston-engine research, could be adapted quickly for study of the turbojet engine. It was because of this, in 1943 when it was no longer necessary for the NACA to concentrate its propulsion research effort on piston engines, that the tools were in hand with which to begin intensive research on the powerplant which would revolutionize the world of aeronautics.

Altitude facilities must duplicate in the laboratory the pressures and temperatures encountered at the altitudes and speeds simulated for the engines under test. Air pressure drops from 14.7 pounds per square inch at sea level to 3.5 pounds at 35,000 feet and to 1.7 pounds at 50,000 feet. At 100,000 feet it is down to 0.2 pound. Air temperature drops from the NACA standard of 59.5° F. at sea level to −67° at 35,000–100,000 feet. The air entering the engines of an airplane is subjected to a ram effect which causes a rise in both pressure and temperature. This ram effect becomes more pronounced as speed increases. For example, the ram effect experienced by an airplane flying at 35,000 feet at twice the speed of sound (M–2) would result in a pressure rise from 3.5 to 27 pounds per square inch, and in a temperature rise from −67° to 250° F.

At the Lewis Laboratory there are two kinds of altitude facilities suitable for testing of full-scale engines. In one, the Altitude Wind Tunnel, an engine may be mounted in a wing or fuselage section, and a study made of air flow around the outside of the engine as well as through it. When the tunnel was first used in 1944, it was for investigation of the operating characteristics of the General Electric I–16, that company's first improvement on the Whittle design, as installed in a Bell P–59. Originally, the tunnel could simulate a top speed of 500 miles per hour and an altitude of 30,000 feet, but within a relatively short time it became
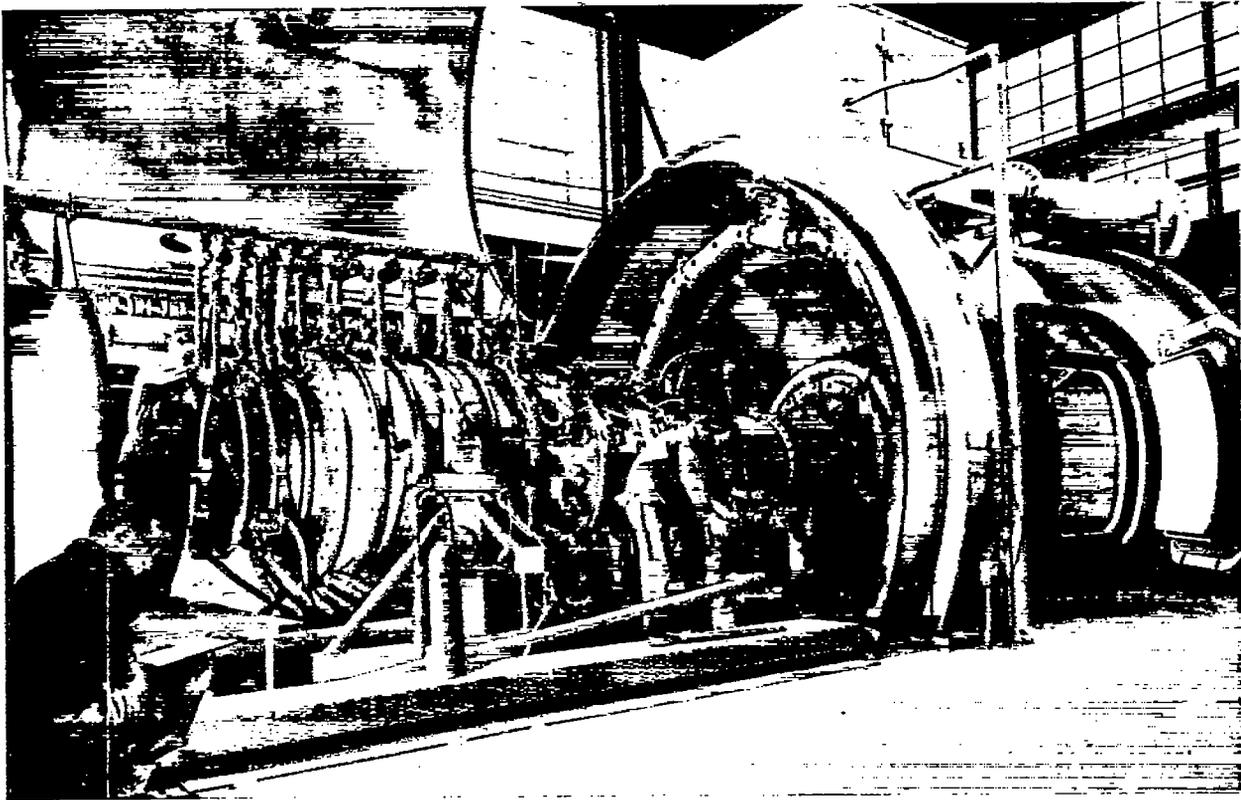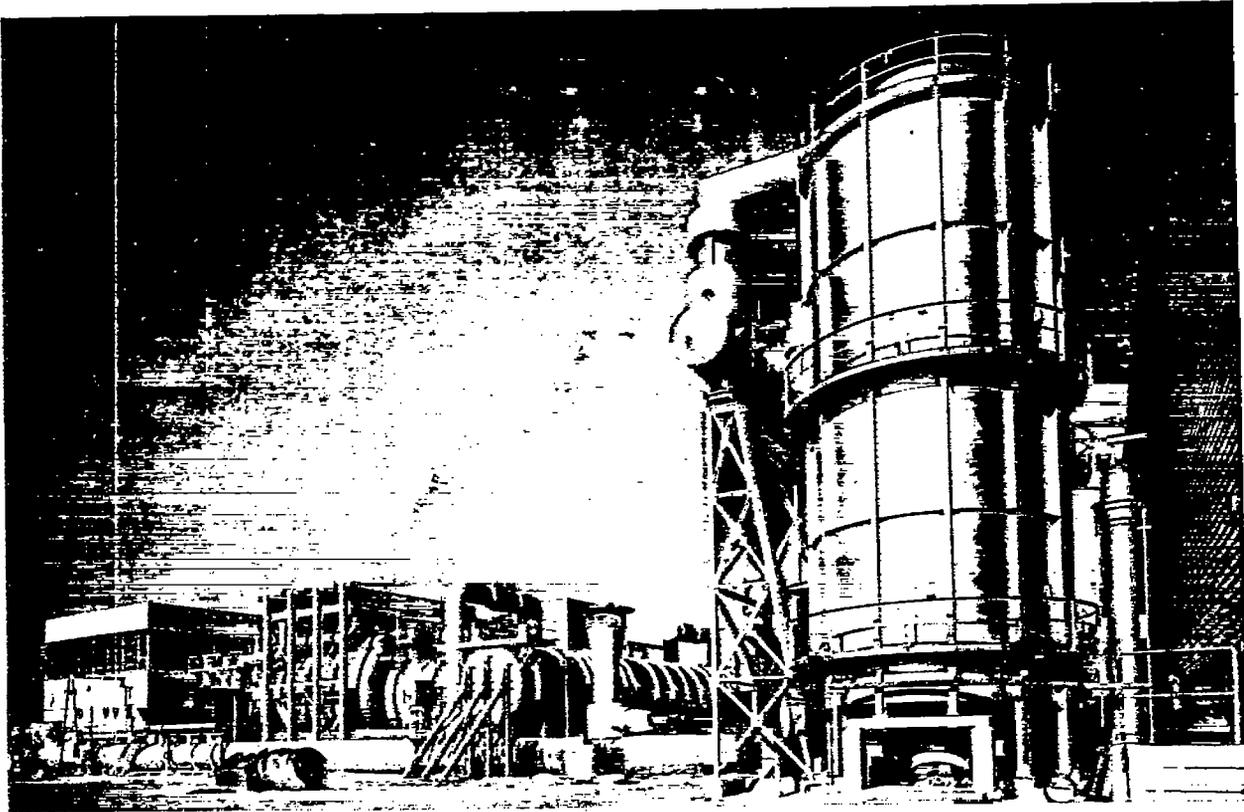
(Upper) Exterior view of new facility at Lewis Flight Propulsion Laboratory where the largest turbojet engines now under development can be tested through their full range of power and altitude. (Lower) Interior view of altitude tank opened up to show test set-up for large-scale combustion tests.

necessary to duplicate altitude conditions of 50,000 feet. During 1952, the capabilities of the tunnel were again increased substantially, by raising the original capacity of the exhausters, which evacuate the test chamber to whatever degree of vacuum is required to duplicate conditions at the desired altitude, from 200,000 to 375,000 cubic feet per minute.

The second type of altitude facility at the Lewis Laboratory for full-scale testing duplicates internal air flow conditions. This requires a ram air supply and a refrigeration system to duplicate the pressure and temperature conditions encountered over the range of flight speeds and altitudes desired. Exhausters subject the gases leaving the engine to a pressure equivalent to the altitude conditions being simulated, and also provide cooling. To permit operation of the several "tanks" at Lewis, exhauster capacity of 400,000 cubic feet per minute was provided, enabling simulation of operating conditions at altitudes of 60,000 feet and higher.

Because the turbojet engine is basically an air-heat machine, its production of greater thrust is limited by the amount of air it can handle efficiently. In the few years this type of powerplant has been under development, its air-handling capabilities have increased enormously. The earliest engines handled hardly 25 pounds of air per second; turbojet powerplants now in full production require 100 pounds of air per second or more, and tomorrow's engines will be even more voracious. During this same brief period the production of useful thrust has increased correspondingly from 1,500 pounds or less to more than 6,000.

This rapid increase in the amount of air required by the more powerful turbojet engines has had the effect of forcing a similar scaling up of the machinery required to operate altitude testing facilities. At the Lewis Laboratory this increase in requirements has been met in two ways.

First, the existing exhauster equipment has been connected by a system of cross piping, which enables the exhausters to be operated collectively as a unit or individually. Similarly, the refrigerated air and combustion air production equipment has been linked for pool operation. From a central station the control engineer can readily supply the test cells with their particular air requirements.

Second, a new research facility, the Propulsion Systems Laboratory, was constructed. Incorporating many improvements both in the altitude exhaust vacuum system and in the other process systems needed to provide altitude conditions, the new equipment has its own exhausters with a total capacity of 825,000 cubic feet per minute, which may be connected with the other exhauster equipment at the Laboratory.

Such facilities are vital in the investigation of the aircraft engines of today and tomorrow. Without them altitude research would be reduced to a crude cut-and-try projection of information gained either from tests at sea level, or flight test which is becoming less practicable as engine performance potentials exceed the performance capabilities of test-bed airplanes. Used effectively these laboratory facilities can contribute greatly to the further improvement of the powerplants specified for the faster, higher flying aircraft of tomorrow.

FLUTTER PROBLEMS PRESENT NEW CHALLENGE TO RESEARCH SCIENTISTS

Flutter, which had been effectively restrained if only imperfectly understood in pre-World War II days, has reappeared to challenge the best efforts of both the aerodynamicist and the structures specialist. Today's airplanes, with their very thin, swept wings, fly at or near the speed of sound, and maneuver at very high altitudes. But their gains in performance have been at the cost of greater susceptibility to flutter.

Flutter was a serious problem in World War I and for years afterwards. It manifested itself frequently during dives, sometimes so violently as to cause the airplane to disintegrate in flight.

Basically, flutter is vibration of some part of an airplane, excited by the imposition of air loads. Most early cases of flutter affected one of the airplane control surfaces, such as the aileron, and a cure was found by the addition of mass balance to the affected part. In the 1930's, Theodorsen delineated the fundamental mechanism of flutter, and methods were developed for calculating safe design limits. With increasing use of all-metal construction, the relatively slow airplanes of the day, when designed on a strength basis only, were sufficiently rigid and sturdy to escape the occurrence of flutter. However, at the much faster speeds of today's airplanes, and with the thinner, heavier and more flexible construction now used, airplanes must be designed for flutter as well as for strength right from the beginning.

The flutter problem has become more complex and difficult in the postwar period as designers seek to use extremely thin wings on airplanes to be flown ever faster, ever higher. In attacking the problem, the vibratory characteristics of the structure have to be studied together with the nature of the air loads imposed on the structure. It is necessary to consider the vibrational characteristics of many different types of wings. The thin wing, which does not remain undistorted in its own plane, introduces a new complication. Once, it was sufficient to consider only the more simple vibrational characteristics. Now, it is being found that unless the flutter analyses take into account as many as possible of the characteristics, the results will be seriously in error.
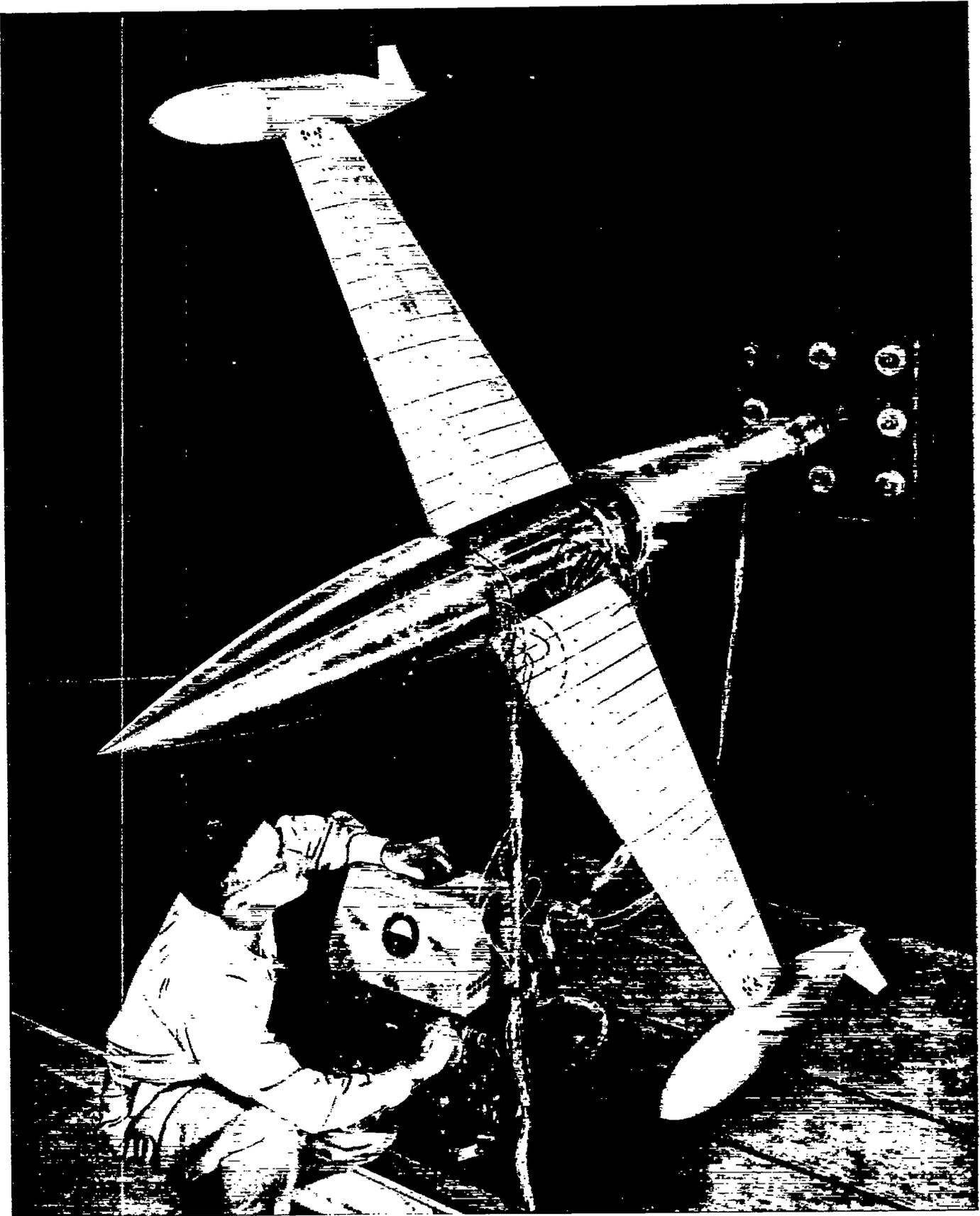
Structures specialist at Langley Aeronautical Laboratory checks instrumentation on dynamic model of wings and tip tanks similar to those of modern high-performance fighter airplanes. When installed in a wind tunnel, the model will be used in flutter investigations.

At the higher altitudes the ratio of air density to airplane density becomes so low that different patterns of flutter vibration and altogether different flutter speeds (the lowest speed at which flutter occurs) may occur as the airplane climbs or dives from one altitude to another. Variable structural stiffness, and the distortions resulting from aerodynamic heating, add further to the difficulty of the problem.

In fact, flutter has become so complex that scientists have been frustrated in attempts even to formulate it theoretically, much less suggest theoretical solutions. Much research is being devoted to theoretical attacks on the problem. Meantime, the most effective solutions are resulting from experimentation.

Experimental research of two kinds is being conducted on flutter by the NACA. One requires separate investigations of the air loads on a vibrating wing, as well as the vibratory characteristics of practical wings. The second involves measurement of the flutter speeds of actual wings. This latter method includes study of a group of wings which represent a systematic variation of some structural or geometric pattern. In this work, thousands of tests have been made using simplified models. Much of this research is performed in wind tunnels, although for investigations of flutter in the transonic speed range, both free-falling and rocket-powered models have been used.

Some of the newest airplanes, in particular large bombers, have relatively flexible, thin wings. On the span of these are located concentrations of weight, such as engines, fuel pods, rockets, etc. The variables which must be considered in studying the vibration characteristics of such airplanes are so large that analysis is all but impossible. In these cases, tests are made using models which duplicate the dynamic characteristics of the full-scale airplane.

The research scientist is using every resource at his command. Special pressure cells, having a fast response, enable more accurate determination of the air loads which may cause flutter. Large, high-speed computing machines are being used to enable rapid mathematical consideration of a greater number of vibration characteristics for a wing under study. One of the large wind tunnels at the Langley Laboratory is being modified to enable round-the-clock flutter testing of dynamic models.

Flutter today is, at best, an art, not a science. But unless flutter is to impose limitations upon performance, the research scientist must learn how to rationalize the many assumptions and cut-and-try simplifications, now used in desperation, into reliable, useful theory. When that day comes, and only then, flutter analysis will indeed have become a science.

STABILITY AND CONTROL AT HIGH SPEED HAS BECOME CRITICAL PROBLEM

Since the end of World War II, efforts by the United States and other powers of the world to fly faster than sound have been so successful that during the past year American fighters in considerable numbers have repeatedly engaged enemy fighters in combat in Korea at low supersonic speeds. But with the attainment of today's higher speeds and higher altitudes, stability and control problems have become greatly aggravated. By no means are these the only aerodynamic problems still unsolved, but satisfactory answers to them are imperative if our supersonic aircraft are to serve as steady gun platforms or as vehicles for precision bombing.

In order that the problems could be attacked intelligently, it became necessary to be able to evaluate precisely the measured or predicted stability and control characteristics of an airplane, and much study has been devoted to establish suitable stability and control requirements. These studies, in which the NACA participated, led to establishment of formal flying qualities specifications by the military services. Originally, the experience upon which these requirements were based had been in propeller-driven, straight-wing airplanes flown mainly below 30,000 feet; in recent years, similar studies have been conducted using jet aircraft. The introduction of the high-thrust turbo-jet engine lifted both the operating speeds and altitudes to the point where radical changes in airplane design were required to realize the potential provided by the new engines.

One result of the sharp rise both in speed and altitude has been a significant deterioration in dynamic stability. For example, when the steady flight of a propeller-driven, subsonic airplane is disturbed, as by a side gust, a lateral oscillation occurs which may be expected to subside quickly as the aircraft returns to its original steady flight. In the case of a supersonic fighter, however, the same side gust might be expected to cause a more pronounced and rapid lateral oscillation which would persist for a larger number of cycles before damping out. The problem, then, is to devise an "aerodynamic shock absorber" which will give an acceptable degree of dynamic stability at the higher speeds now being attained.

Extensive NACA flight research has been conducted at both the Langley and Ames Laboratories, directed at isolating and analyzing the effects of lateral oscillation characteristics on the tracking performance of fighter-type airplanes, i. e., their suitability as a gun platform. One means of gathering such information has been through use of conventional fighter airplanes fitted with special mechanical or electrical devices which enable its dynamic stability—and consequently, its handling characteristics—to be varied in flight, thus simulating accurately these characteristics for a wide range of high-speed airplane designs. Three airplane types, a Grumman F-6-F, a Lockheed TO-2, and a North American F-86 have been so equipped.

Use of variable stability aircraft provides a ready means not only of studying the flying qualities of existing aircraft, but also of learning—in advance—how acceptable the dynamic characteristics of future supersonic airplanes will be to pilots. For example, the dynamic stability and control characteristics of the Douglas D-558-II at high altitudes and high speed were simulated in the F-6-F so that research pilots could become well acquainted with them prior to actual flight at such speeds and altitudes. Pilots of the Air Force, Navy, and the aircraft industry, as well as the NACA, have flown the F-6-F rigged to simulate the dynamic characteristics of several new airplane designs in preparation for initial flight tests.

As more is learned about the range of lateral oscillation characteristics which will result in acceptable gun tracking or other tactical maneuvering requirements, the problem becomes one of designing the airplane to possess satisfactory oscillation characteristics without compromising seriously other fundamental performance requirements. Extensive NACA research results are enabling designers to improve dynamic behavior in high-performance airplanes through variations in aerodynamic design. Although it has been found that the undesirable oscillation characteristics can be lessened by such attention to design detail, it is becoming increasingly apparent that to obtain satisfactory dynamic behavior over the range of flight speeds and altitudes now possible, purely aerodynamic means may not suffice.

With respect to higher-speed aircraft, it appears that one logical method of obtaining desirable dynamic characteristics is the use of artificial-stability systems. In such devices, which are being used increasingly, the control surfaces are actuated automatically to improve the plane's dynamic characteristics while the pilot retains control. A simple artificial-stability system measures the airplane's directional motion, and transmits this information to a motor which moves the rudder so as to damp the motion quickly. In a more complicated system, additional information may be fed into motors moving both the rudder and ailerons.

But not even these powerful artificial-stability devices will enable sufficiently precise flight by tomorrow's fighters. As flight speeds increase, the pilot is forced to perform a growing list of duties, with less time available in which to do them. Because of human limitations, it is necessary to use automatic-control equipment which assumes complete control of the airplane during critical maneuvers. Such equipment obviously will be complex and may well be heavy. But it will compute and apply the necessary corrective control movements rapidly and accurately.

The foregoing is a brief account of but one segment of a many-pronged research attack by the NACA to provide solution to the increasingly critical problems of stability and control in high speed flight.

RESEARCH OFFERS HOPE FOR REDUCTION OF CRASH-FIRE HAZARDS

Aeromedical research in recent years has shown that very high decelerations can be withstood by a human, provided they persist for only an extremely short time. One consequence of this finding has been a realization that the number of survivals from crash-landing types of airplane accidents might be increased substantially if the fire which so often follows could be prevented. With modern air transports continuing to grow in passenger capacity, the potential good from discovery of ways of reducing sharply the incidence of fire in crash landings becomes even greater.

During the past 30 years a very considerable effort has been made to reduce aircraft fires. Work has been done by the Military Services, civilian agencies of the Government, educational institutions, fuel manufacturers, and aircraft manufacturers and operators. These investigations in not a few instances have been extensive, but except in rare instances they were more concerned with seeking new methods of applying extinguishing agents to a fire than in exploring the more fundamental "how's" and "why's" of crash fires. Nor had there been thorough assessment and verification of previous work, both in this country and abroad.

The search for effective extinguishing agents with which to quell fire is ages old. Two centuries ago Cavendish and Priestley were making inquiries into the fundamental nature of combustion, and from their experiments came awareness that if a minimum amount of oxygen was not present, there would be no fire. Doubtless, one impelling reason for these earliest of the scientific attacks upon the problem was the need to discover methods whereby disastrous mine fires could be avoided or quickly quelled—a need that still persists.

In the intervening years, hundreds, if not thousands of chemicals have been proposed to extinguish fire. Especially in the case of fire, where only one "fuel" is being consumed, many of these agents have proved of great value. But an aircraft fire is seldom so simple. The "fuels" are many, and many sources of combustion are ever present.

In 1947, a fire panel of research specialists was established at the Lewis Flight Propulsion Laboratory, under the cognizance of the NACA's Committee on Operating Problems, and directed to review existing information about aircraft fires to determine what new or further research might offer promise of a substantial reduction of the aircraft fire hazard in flight and following crashes. During this survey, one fact stood out—

precise knowledge about how aircraft fires were started and how they spread was essential. Hardly less critical was the need for a better understanding of the basic actions of fire-extinguishing agents.

To obtain guidance from specialists in planning further research on the problem, the NACA appointed a Subcommittee on Aircraft Fire Prevention. This group conceded that ultimate reduction of the fire hazard would not result from the application of any single improvement, but rather from "an integration into the airplane design and flight operation of new ideas and methods." It recommended to the NACA that a massive attack on the problem be undertaken which would use all of the research resources available. In addition to such fairly obvious effort as more thorough evaluation of all existing literature on the subject and analysis of commercial aircraft accidents during a 10-year period, studies were undertaken at the Lewis Laboratory to learn more about the fundamentals of combustion and ignition sources, and no less, about the chemistry of fire-extinguishing agents.

In 1948 the NACA research panel made a preliminary report which noted that both small-scale and large-scale laboratory tests could be quite convincing, as in the demonstration of the retarded ignition, the slower rate of burning, and the generally less explosive character of low volatility fuel, the answer to the final question—would there be a reduction in the fire hazard from use of such fuel—could hardly be provided by performance of further laboratory bench tests. The consensus was that information at hand, or obtainable from use of laboratory techniques, failed to provide a clear picture of the mechanism of the crash fire. In addition, the problem was so complex as to make an analytical approach unpromising.

Crash tests using multiengine, war-surplus transport airplanes would be required to provide the type of answers still needed to provide answers to the many questions. "The difficulty . . . of the crash tests is recognized, but no other technique appears to serve the same purpose," the subcommittee report observed.

The Air Force in 1949 made available a number of war-weary C–46 transports and C–82 cargo planes for the full-scale crash fire investigation, and the Army provided suitable space at its Ravenna Arsenal, in Southern Ohio, for the work. The crashes simulated a take-off accident in which the airplane fails to become airborne; strikes an embankment; shears off the propellers and the landing gear; strikes trees or poles; ruptures the fuel tanks, and then skids along the ground to a stop. In this type of crash, fuel and oil lines within the engine nacelles are often broken, and the maximum array of potential ignition sources is present. The tests contained the elements of a very severe fire hazard, but from the standpoint of impact, such crashes were considered to be survivable for a majority of the

plane occupants. In the tests the airplanes, loaded with more than 1,000 gallons of fuel and with their engines at full throttle, moved down a 1,700-foot runway to the crash barrier. A monorail, to which the planes were hooked, kept them on course.

High-speed motion picture cameras, located at seven points around the crash area, provided a detailed photograpic record. The planes themselves carried a specially-constructed fire-proof, shock-insulated box filled with instrumentation to measure temperature, combustible vapors, and decelerations. Also, instrumentation was provided to detect fuel-line failures and short circuits or arcs. Timing lights on the planes synchronized the cameras located outside with those in the instrument box. A total of 102 thermocouples, heat registering devices, were installed in the engine nacelles, wing and fuselage, to detect the origin and spread of fire throughout the aircraft structure.

During the course of the crash tests, attention was given, whenever possible, to obtaining information that might be helpful in improving the crash-worthiness of aircraft structures.

Results of the program to date include a much clearer understanding of the mechanism of an aircraft crash fire—why and how a fire starts and spreads. Because the current research was conducted with modern aircraft and more complete instrumentation than previously had been possible, the findings permitted an appreciation of important factors in the problem heretofore not fully recognized.

For example, the manner in which lubricating oil or hydraulic fluid might first be fired under temperature conditions too low to ignite the gasoline fuel was studied in detail. These oil or hydraulic fires then would serve as a torch to ignite the fuel, either in vapor or liquid form. Also, it was observed that cutting the ignition switch on the engines, before the flow of fuel had been stopped, sometimes resulted in fire, as the fuel passed through the engines and was ignited by the hot metal of the tail pipes.

Once the series of crash tests had enabled rather precise establishment of a "standard" set of ignition sources, as well as a better understanding of how the fires, once started, spread, modifications in the crash procedure were made to discover other ignition sources. For example, the plane was made to ground loop, by knocking off only part of the landing gear. Another modification raised the contact angle, between plane and ground, at point of crash to cause more damage to the belly of the plane during impact. One by one, ignition sources—such as electrical wiring, hot metal surfaces of engine exhausts, etc.—were identified and evaluated.

Results of the work performed to date indicate significant reductions in the crash-fire hazard can be realized. What, specifically, needs to be done is currently classified because of military application of the data, but the information has been made available both to the manufacturing industry and operational personnel of the air transport companies. Further research, now in progress, offers the hope of still greater reduction of the crash-fire hazard.
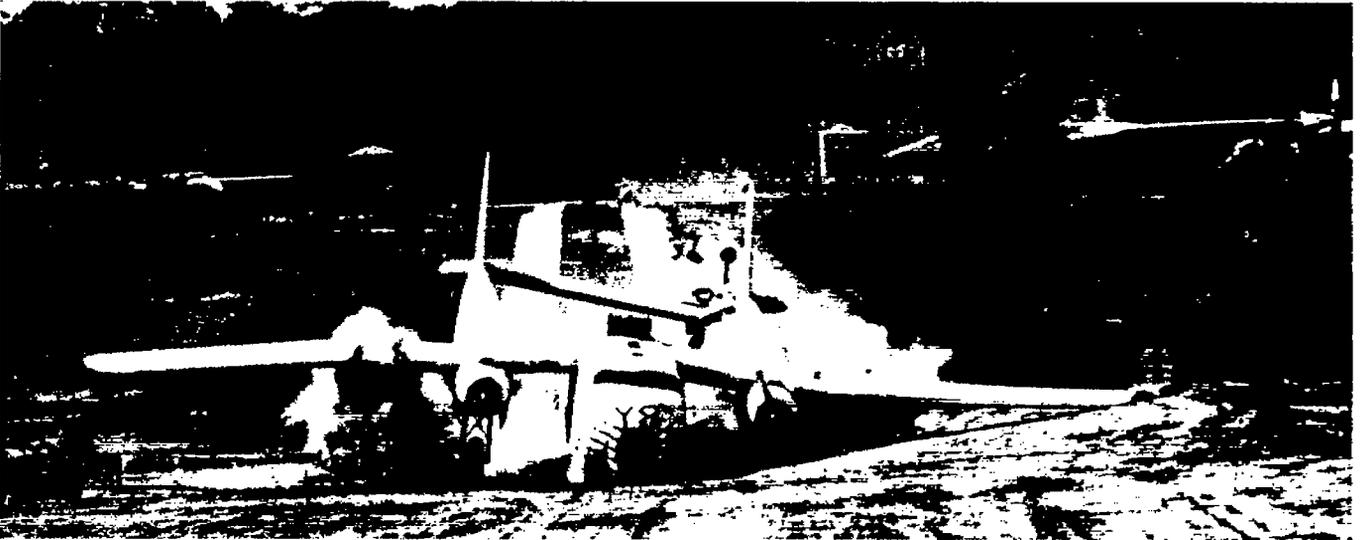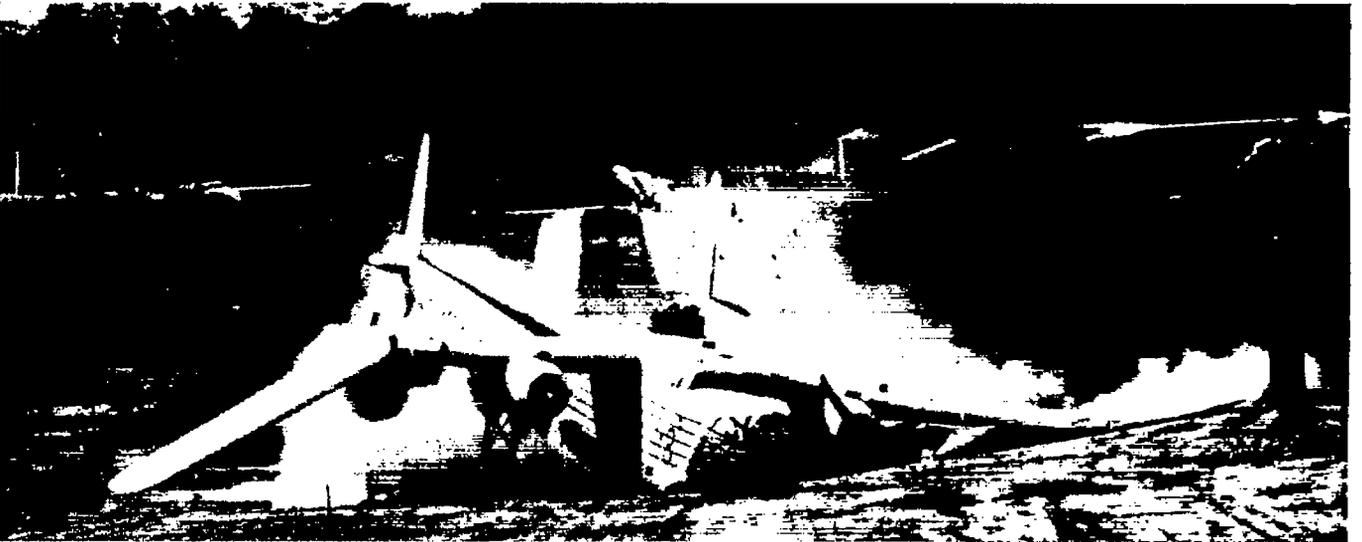
The six high-speed photographs on these two pages show the crash procedure followed by research scientists of the Lewis Flight Propulsion Laboratory in the study of the sources of fire ignition and ways to prevent fire.   In this crash the embankment was shaped so as to cause the airplane to ground loop.
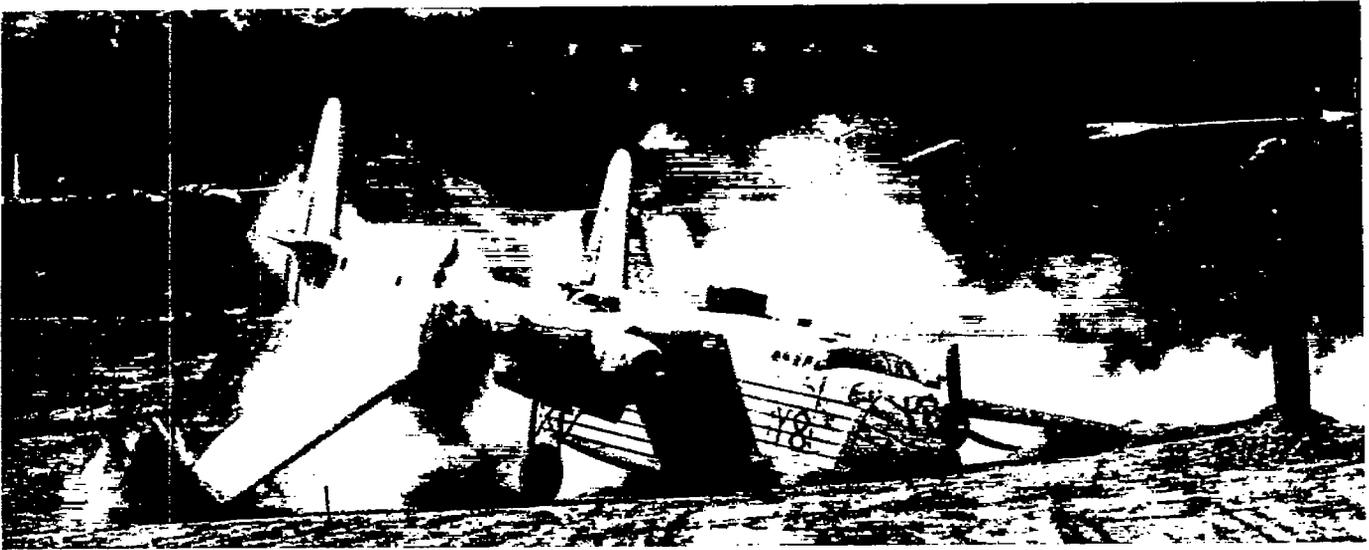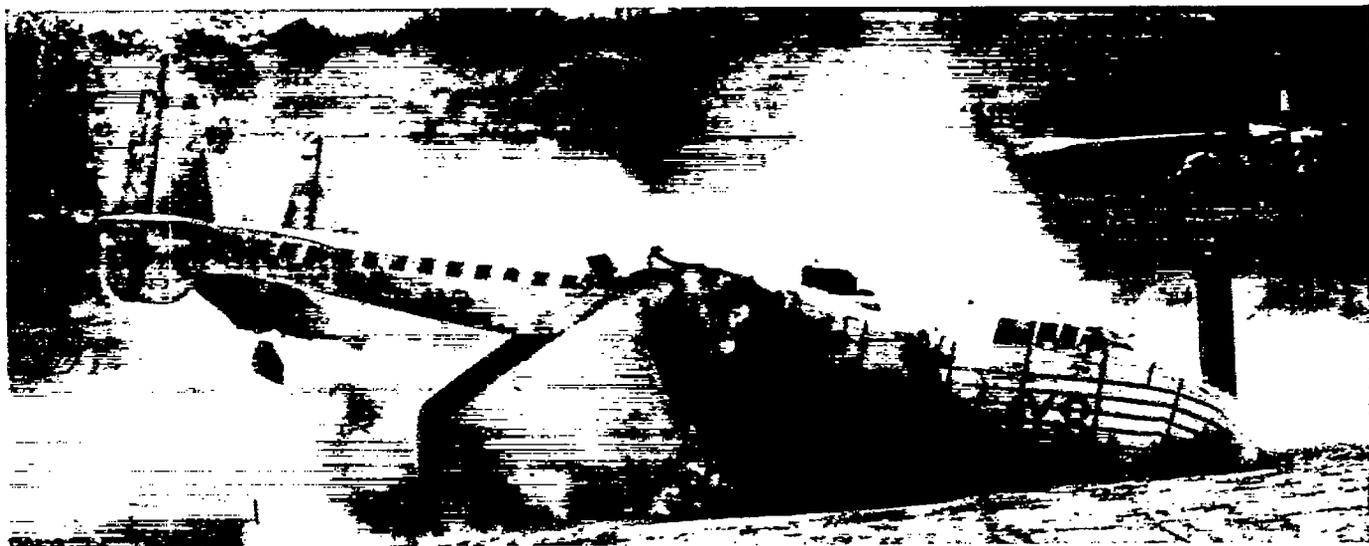
In photo 1, the airplane approaches the barrier, engines at full throttle. In 2, it has hit the barrier. Photo 3 shows structural damage as the airplane begins to ground loop. In photo 4 it is skidding along the ground. Photos 5 and 6 show the fire hazards resulting from such a crash.

AERODYNAMIC RESEARCH

During the past year experimental flights with piloted research aircraft have been extended to higher altitudes and speeds than previously attained in man-carrying aircraft. These successes, however, have served again to indicate critical new research problems and also to re-emphasize some problems previously recognized. As a consequence, it has been necessary to redirect certain aerodynamic research programs in an effort to provide the information required in the design of efficient transonic and supersonic aircraft. These much-needed research data are not only being obtained by rocket-powered supersonic free-flight models and experiments in subsonic and supersonic wind tunnels, but also from investigations through the speed of sound in the Committee's new transonic wind tunnels. The scope of the problems now being emphasized is broad and includes detailed studies of factors affecting dynamic stability and performance at transonic and supersonic speeds. It has also been necessary to continue fundamental research on aerodynamic flows, not only at high supersonic and hypersonic speeds, but also at subsonic speeds, in an effort to establish new concepts which might offer promises of large gains in aircraft and missile performance.

The accomplishments of the Committee's laboratories during the past year and the new research programs which have resulted have been followed closely by the Committee on Aerodynamics and its Subcommittees on Fluid Mechanics, High-Speed Aerodynamics, Stability and Control, Internal Flow, Helicopters, Propellers for Aircraft, and Seaplanes. These aerodynamic subcommittees have also aided in the planning and integration of research programs in this major field of NACA activity.

In order to promote the early use of research results in the design and development of airplanes and missiles, the practice of holding technical conferences with representatives of the military services and the aircraft industry was continued during the past year. A technical conference on the aerodynamic design problems of supersonic guided missiles was held in the fall of 1951 at the Ames Laboratory. A similar conference on high-speed airplane aerodynamics was held at the Langley Laboratory in December 1951.

In the sections which follow, descriptions are given of some of the Committee's recent unclassified work in aerodynamics.

FLUID MECHANICS

Theoretical Aerodynamics and Gas Dynamics

In Technical Note 2748 work has been continued on the general problem of whether a smooth two-dimensional potential flow past a prescribed solid boundary can exist at stream Mach numbers exceeding the critical value. The solid boundary chosen in this work is a sinusoidal wall extending to infinity in both directions. Several new results of considerable importance have been obtained since the initial phase of this problem was completed and published as Technical Note 2383 (reported in the last annual report); they are: (1) A procedure has been developed for the analytic solution of the recursion formulas which arise from the method of integration in series and (2) a numerical test of convergence, applied to the power series in the transonic similarity parameter representing the local Mach number distribution at the boundary, definitely shows that smooth symmetrical potential flow past the wavy wall is no longer possible once the critical value of the stream Mach number has been exceeded.

The basic concepts and assumptions involved in the derivation of the transonic similarity rules have been reviewed and discussed in Technical Note 2687. The region of valid application of the rules is shown to be restricted to Mach numbers close to unity. It is pointed out, however, that theoretical grounds exist for using the transonic similarity parameters as a means of extrapolation for thickness-ratio effects in the range of thickness ratios of main interest in current transonic aircraft design.

The use of the method of characteristics for the solution of supersonic-flow problems requires numerical procedures which are lengthy and involved and which must be repeated for each set of boundary conditions. In Technical Note 2515 a method for linearization of the method of characteristics is presented. It has been assumed in the method that the flow field can be represented as a basic flow field determined by nonlinearized methods and a linearized superposed flow field that accounts for small changes in boundary conditions. The method has been applied to two-dimensional rotational flow where the basic flow is potential and to axially symmetric problems where conical flows have been used as the basic flows. The method has also been applied to slender bodies without symmetry and to some three-dimensional wing problems where two-dimensional

flows can be used as the basic flow. Both of these latter problems were unsolved before in the approximation of nonlinearized flow.

In Technical Note 2630, a solution of the Navier-Stokes equation for source and sink flows of a viscous heat-conducting compressible fluid is presented for the case of constant total-flow energy. The nature of the general solutions for flow with arbitrary Prandtl number and with heat addition is discussed; furthermore, the manner in which the familiar heat-conduction effects combined with the peculiar viscous effects solely due to compressibility, sometimes called the longitudinal viscous effects, influence the flow through a curved minimum section joined to a sink flow is discussed. A discussion of the second viscosity coefficient from the gas-dynamics approach is also given.

The flow about curved airfoils has been investigated analytically at high supersonic speeds assuming air behaves first as an ideal and then as a calorically imperfect gas. Effects of caloric imperfections are manifested in disturbed flow fields at high Mach numbers. It has been found in a first investigation reported in Technical Note 2646 that for ideal gas flows the shock-expansion method accurately predicts pressures on curved airfoils over wide ranges of deflection angles at high Mach numbers. The shock-expansion method and the method of characteristics were generalized to consider the caloric imperfections of air at local temperatures up to 5,000° R. A second investigation reported in Technical Note 2729 has been completed which treats in detail the characteristics of supersonic flow in the region of the leading edge of curved airfoils. Charts and tables are presented to facilitate the determination of the flow properties for the case of air behaving as an ideal gas and also for air behaving as a calorically imperfect gas.

Technical Note 2546 presents the results of an investigation to measure the true viscosities of nitrogen and air at 306° and 273° K. at pressures from 500 to 0.0005 millimeter of mercury and at 194° and 79° K. at pressures down to 0.3 millimeter of mercury. In the region in which the thickness of the gas layer is many times the mean free path of the gas, the "slip coefficient" (defined as the proportionality constant existing between the slip velocity and the velocity gradient) was found to show a linear dependence on the inverse pressure down to about 0.02 millimeter of mercury. In the region in which the pressures are sufficiently low to permit the neglect of collisions between molecules, theory has indicated that the viscous drag should be directly proportional to the pressure and inversely proportional to the square root of the temperature. Results of this investigation indicate that this relationship was reached at pressures a little below 0.02 millimeter of mercury. This work was conducted at Ohio State University under contract with the NACA.

In a contract study, Iowa State College reviewed the literature on sonic studies of the problem of the excitation of molecular vibrations by collision and reported the work in Technical Note 2537. The theory on which the interpretation of almost all the sonic work has been based is discussed rather qualitatively in some detail. The principal experimental programs are described and a table of most of the available results is included.

An analysis has been reported in Technical Note 2511 which treats transition flows over two cylindrical surfaces by an iteration procedure. The velocities near the midchord, the critical free-stream Mach numbers, and the extent of the isentropic supersonic regions were calculated to four approximations for a Kaplan section and to six approximations for an elliptic section. The results are presented as an expansion in powers of the Karman transonic similarity parameter and its maximum value for the convergence of the expansion was estimated in each case.

In Technical Note 2725 expressions are derived for computing the form of an oblique shock wave as it passes through supersonic regions in which the static pressure, stagnation pressure, and stagnation temperature have in the general case arbitrary, continuous variations. For the particular cases of passage through supersonic shear flow and through Prandtl-Meyer flow, computation is simplified by means of charts of shock angle against upstream Mach number.

At New York University under contract to the NACA, a solution for compressible fluid flow past an elliptic cylinder by means of the variational method has been obtained and reported in Technical Note 2666. The solution was obtained as a function of thickness ratio and free-stream Mach number. Numerical examples have been carried out for several thickness ratios and Mach numbers and the results have been compared with those obtained by other methods. It is shown that the variational method yields good results for flow past a thick body at a low Mach number as well as for flow past a thin body at a high Mach number.

The variational method also has been applied by New York University under NACA sponsorship to transonic flows with shock waves and the results are presented in Technical Note 2539. By modifying Bateman's variational principle for irrotational flows, it is shown that a variational principle for flows with rotation and variable entropy can be obtained. By applying this variational principle to the regions of flow behind shock waves and Bateman's original principle to the other regions in the fluid, shock equations can be directly obtained. A procedure for computing numerical solutions for such flows is suggested, and a numerical example is carried out. Above certain limiting high Mach numbers the results show that irrotational flow fails. However, by inserting shock waves and allowing

a part of the flow to be rotational, computation indicates that a solution exists again.

The flow behind the attached curved shock near the nose of an axially symmetrical body placed in a uniform stream has been investigated at the Massachusetts Institute of Technology under NACA contract by considering the perturbations from the initial Taylor-Maccoll conical solution. The first-order perturbation yields the ratio between the initial radii of curvature of the shock wave and the body. When higher-order perturbations are included, a regular shock wave near the nose leads to a body shape which has a logarithmic singularity at the nose. It seems, therefore, that, for a given regular body, the shock-wave shape probably has a singularity at the vertex, although the initial radius of curvature remains finite. Numerical results have been obtained (Technical Note 2505) for the first-order perturbation equations, covering the cases with initial semivertex angle or 10°, 20°, and 30°, each at five different Mach numbers ranging approximately from the minimum 1 for an attached conical shock to a value around 5.

The method of power-series expansion in solving the local flow pattern behind a detached shock was proposed by Lin and Rubinov. In Technical Note 2506 the limitations of the method are discussed and the practical procedure for approximating the power series with a 2nth-degree polynomial by cutting off the remaining terms is investigated. This work was also conducted at the Massachusetts Institute of Technology under NACA sponsorship.

At Johns Hopkins University an investigation of the hodograph method as it is applied in general to the problem of compressible flow has been made under contract to the NACA and is reported in Technical Note 2582. In this report the hodograph equations are given in various canonical forms which are convenient for obtaining solutions in the different flow regimes.

In Technical Note 2451 the Poisson integral involved in the determination of the change in velocity distribution resulting from a change in airfoil profile in parallel incompressible flow is solved. First, three well-developed numerical methods of evaluating this integral, all based on the division of the range of integration into small equal intervals, and the difficulties involved in each method, are discussed. Then a new method, based on the use of unequal intervals, is developed, and compared with the other methods by means of several examples. The new method is found to give good results for both the direct and inverse airfoil problems and is easily adaptable to rather complicated problems. It is particularly recommended for all those functions where steep slopes exist in small portions of the region to be integrated. This work was conducted at Stanford University under NACA contract.

The flow of a compressible fluid through a channel having locally supersonic regions has been studied by using the Tricomi equation in the hodograph variables as an approximation in the sonic region to the equation of flow of an irrotational, inviscid gas. It is shown in Technical Note 2547 that this is equivalent to studying the flow of a gas having a pressure-density relation matching the isentropic relation to the third derivative at the sonic point. A one-parameter family of solutions of the Tricomi equation is used which provides symmetrical accelerated-decelerated flows. The variation of this parameter alters the Mach number at the center of the throat, the velocity distribution and gradient along the center streamline, as well as the shape of the channel. As specific examples, flows are computed having Mach numbers equal to unity and to 0.86 at the center of the throat section. Constant-velocity lines are plotted and it is found that the velocity gradient becomes zero at three places along each streamline outside of a limiting streamline for values of the parameter greater than zero ($M < 1$ at center of throat section). For the parameter equal to zero ($M = 1$ at center of throat section), the velocity gradient along the streamlines and the curvature is discontinuous at all points of the two characteristics which meet the center streamline. Other solutions to the Tricomi equation are discussed which may be used to formulate channel flows. The exact nature of these flows has not yet been investigated. This work was conducted at Brown University under contract to the NACA.

The theory initiated by Prandtl and Taylor on the behavior of turbulence carried through a wind tunnel contraction has been extended in Technical Note 2606 principally by introduction of the spectrum concept. Thereby, the selective changes in the components of turbulent intensity have received a more accurate treatment. In addition, contraction-induced changes in the spectrum and correlation tensors have been considered for the first time and marked changes in the one-dimensional longitudinal spectrum, that recorded by a hot-wire instrument, have been predicted.

In an investigation at the National Bureau of Standards sponsored by the NACA a generalized potential theory applicable to nonadiabatic and rotational flow has been developed. With the use of this theory the action of heat sources on the flow has been studied, and the heat delivery in a compressible flow at subsonic and supersonic speeds has been calculated. The results, which are presented in Technical Note 2436, show the effect of compressibility and the nonlinear cooling. Applications of the results to hot-wire anemometry are discussed.

In an investigation carried out at the California Institute of Technology under contract with the NACA, measurements of the spectrum and correlation functions at large Reynolds number ($RN \approx 10^5$ based on the

grid mesh) have been made, as well as a series of accurate spectrum measurements at lower Reynolds number ($RN \approx 10^4$). The results are presented in Technical Note 2473 and are compared with theoretical laws proposed in recent years.

Boundary Layers and Turbulence

A simplified procedure has been developed for the calculation of compressible laminar boundary layers with arbitrary free-stream pressure gradients. The analysis, based on the Karman-Pohlhausen integral method, is presented in Technical Note 2531. The results enable velocity and temperature profiles, momentum and displacement thicknesses, and wall shear stress to be obtained for flows over both two- and three-dimensional bodies.

The laminar compressible boundary layer over an insulated flat plate moving with time-dependent velocity has been given detailed analysis in Technical Note 2471. A technique is given for predicting whether the motion is quasi-steady or if the classical "starting from rest" solution applies. Computations are made to show deviations of the velocity and temperature profiles from the quasi-steady state. The method may also be applied to determine whether quasi-steadiness may be assumed in problems involving unsteady laminar flows with pressure gradient and probably unsteady turbulent boundary layers as well.

An analysis of the laminar boundary layer on a circular cone at angle of attack to a supersonic stream has been presented in Technical Note 2521. A perturbation technique is employed to determine the influence of small angle of attack on such boundary-layer quantities as skin friction, boundary-layer thickness, viscous lift, drag, and pitching moment.

In Technical Note 2722 a method is presented for determining the "displacement surface" of a known three-dimensional boundary-layer flow in terms of the mass flow defects associated with the profiles of the two velocity components parallel to the surface. Several examples are discussed and numerical values given for the specific case of a cone at small angle of attack to a supersonic stream.

An analysis of the effect of slip on compressible laminar boundary-layer skin friction has been made and is presented in Technical Note 2609. The extent to which the no-slip boundary-layer theory is valid and the magnitude of the slip effect are discussed.

An experimental investigation has been conducted in the Langley low-turbulence pressure tunnel on an NACA 64A010 airfoil section equipped with 82 suction slots (41 per surface) for the purpose of increasing the extent of laminar boundary-layer flow. The results of this investigation, presented in Technical Note 2644, indicated that laminar flow could be maintained over 91-percent chord up to Reynolds numbers as high

as 10×10^6. This result, however, was obtained on only one surface of the model. On the assumption that both surfaces of the model could have been made equally effective in maintaining laminar flow, a drag coefficient of about 0.0024 (including the drag coefficient equivalent of the suction power) would have been obtained as compared with 0.0042 for the plain smooth airfoil. One significant observation was the increasing difficulty encountered in obtaining full-chord laminar flow at higher Reynolds numbers because of the increasing sensitivity of the flow to minute surface irregularities and slight inaccuracies of slot-entry contour.

In order to investigate the possibility that an increase in boundary-layer thickness in regions of pressure gradient and flow through the surface can increase the local critical Reynolds number more than the local boundary-layer Reynolds number, computations have been made (Technical Note 2752) by combining the Schlichting method for the computation of the laminar boundary layer with the Lin method for the calculation of the critical Reynolds number of a velocity profile. The computations indicate that, in a region of falling pressure on an impervious surface, an increase in boundary-layer thickness can cause the velocity-profile shape to be changed enough by the increase in effective pressure gradient to increase the ratio of the local critical Reynolds number to the local boundary-layer Reynolds number.

In order to obtain some information on the effects of an axial velocity on flow fields involving turbulent motion, an experimental investigation was made of the pressure distribution about a circular cylinder at various angles of yaw. The results, presented in Technical Note 2463, indicate that the flow and force characteristics in the range of Reynolds number near and above critical, based on normal velocity components, cannot be determined by only the component of flow normal to the cylinder axis. For example, the critical Reynolds number decreased and the supercritical drag coefficient, based on the flow normal to the leading edge of the cylinder, increased with an increase in the angle of yaw up to 60°. In addition, the localized regions of laminar separation that appeared in the supercritical range of Reynolds number on the unyawed cylinder were not as well defined at yaw angles of 15° and 30° and completely disappeared at yaw angles above 45°.

The Von Karman momentum equation gives a relation between the changes in boundary-layer momentum and the external stresses of pressure gradient and wall shear, which applies equally as well for turbulent boundary layers as for laminar boundary layers. For turbulent boundary layers, however, problems arise in the interpretation of momentum and in the application of the equation to experimental data. A study of the Von Karman momentum relation with respect to its application to turbulent boundary layers in a positive

pressure gradient is presented in Technical Note 2571. Although this momentum relation for turbulent boundary layers contains momentum terms due to the fluctuating motion as well as momentum terms due to the mean motion, the general practice has been to neglect the momentum terms due to the fluctuating motion. Data were obtained from Technical Note 2133, reported in the last annual report, and Technical Memorandum 1285 with which the terms due to both the mean flow and the fluctuating flow could be evaluated. The results indicate that the streamwise derivative of the turbulent longitudinal momentum may be large near separation and therefore should be considered when the Von Karman momentum relation is used for turbulent boundary layers near separation.

There is presented in Technical Note 2692 a derivation of the form of the incompressible turbulent skin-friction flow for an insulated flat plate made in such a way that it may be extended to compressible flows. The ratio of compressible to incompressible skin friction is obtained and the results are shown to be in agreement with existing experimental results.

A number of the most promising integral methods for solving the compressible-laminar-boundary-layer equations approximately have been investigated in order to determine a computationally convenient and sufficiently accurate method of calculating boundary-layer characteristics. The chief methods considered were the one-parameter Karman-Pohlhausen method, with three different assumptions for the velocity profiles, and the two-parameter method, with two different assumptions for the velocity profiles. Comparisons have been made with exact solutions for skin-friction and heat-transfer coefficients, velocity profiles, velocity derivatives, and especially laminar-boundary-layer stability. It was found that the Karman-Pohlhausen method with a sixth-degree polynomial as the velocity profile is the most suitable for many practical purposes. This work was carried out at the Poytechnic Institute of Brooklyn under contract to the NACA and is presented in Technical Note 2655.

Theoretical analyses of the effect of slip on the flow of a rarefied gas near a stagnation point and in a boundary layer on a flat plate have been made at the University of California under contract with the NACA. The results, presented in Technical Note 2568, indicate that the stagnation pressure is increased because of the effect of slip but that there is a negligible effect on the flat-plate skin-friction coefficient in the range of application of the analysis.

A device has been developed at the California Institute of Technology to measure local skin friction on a flat plate by measuring the force exerted upon a very small movable part of the surface of a flat plate. These forces, which range from about 1 milligram to about 100 milligrams, are measured by means of a reluctance measuring device. The apparatus was first applied to measurements in the low-speed range, both for laminar and turbulent boundary layers. The measured skin-friction coefficients show excellent agreement with Blasius' and Von Karman's results. The device was then applied to high-speed subsonic flow and the turbulent-skin-friction coefficients were determined up to a Mach number of about 0.8. A few measurements in supersonic flow were also made. This research, carried out under contract with the NACA, is described in Technical Note 2567.

At the Massachusetts Institute of Technology several studies of Von Karman's similarity theory and its extension to compressible flows have been made under NACA sponsorship. Technical Note 2541 presents the results of a study of Von Karman's similarity theory, with regard to turbulent shear flow, by using the modern concepts of Kolmogoroff. It was found that the original form of the theory is supported by modern concepts. As an application of the concepts presented in Technical Note 2541, the problem of turbulent boundary layer over a flat plate in compressible flow has been treated (Technical Note 2542). In parallel with Von Karman's theory in incompressible flow, the similarity scales for all the flow variables are derived. Two possible length scales were found, and the significance discussed. In Technical Note 2543 an investigation of the turbulent-boundary-layer flow over a flat plate in compressible flow has been carried out on the basis of the scheme established in Technical Note 2542.

An investigation conducted at the National Bureau of Standards under NACA sponsorship is reported in Technical Note 2475 whereby the feasibility of artificially thickening a turbulent boundary layer on a flat plate was studied. The report shows that it is possible to accomplish substantial thickening and to obtain a fully developed turbulent boundary layer which is free from any distortions introduced by the thickening process. Such a boundary layer should be a suitable medium for fundamental research. For example, it is shown that the turbulence in the outer portion of the boundary layer has an intermittent character.

Aerodynamic Heating and Heat Transfer

One of the fundamental factors in determining heat transfer at supersonic speeds is the boundary-layer temperature-recovery factor. An experimental investigation reported in Technical Note 2664 gives values of the recovery factor of 0.885 ± 0.011 for turbulent boundary layers on a 10° cone and on a 40° cone-cylinder, at Mach numbers from 2.0 to 3.8. The location of boundary-layer transition in these experiments was found to be dictated by the test facility.

Measurements have been made of the local rates of heat transfer through laminar and turbulent boundary layers on a cooled flat plate at a Mach number of 2.4.

Data were obtained for a Reynolds number range of 0.15 million to 3.0 million and for nominal surface temperatures of −40° to 45° F. The temperature-recovery factor, obtained from the heat-transfer data, agreed well with previous experimental flat-plate results. The investigation is reported in Technical Note 2686.

Measurements of average and local skin-friction coefficients for laminar flow on a flat plate are reported in Technical Note 2740. The tests were conducted at a Mach number of 2.4 over a Reynolds number range of 0.72×10^6 to 2.8×10^6.

A method for solving the laminar boundary-layer equations for compressible flow, in the absence of a pressure gradient has been developed (Technical Note 2499) without imposing restrictions on the thermal properties of the fluid medium. Velocity and temperature profiles and boundary-layer characteristics have been computed for Mach numbers from 1 to 10, utilizing experimental values of the heat capacity, viscosity, and conductivity. The analysis shows that an effective temperature, which is a function of the surface temperature and stream conditions and is similar to the recovery temperature, arises naturally and is the proper reference temperature to be used in heat-transfer calculations. The effective temperature and the recovery temperature became identical for the condition of zero heat transfer. The recovery factor and the analogous effective-temperature function decrease substantially with increasing values of Mach number.

An experimental and analytical investigation has been conducted at the Johns Hopkins University under contract with the NACA to study some features of the turbulent heat diffusion behind a heated wire perpendicular to a flowing isotropic turbulence. The mean temperature distributions have been measured with systematic variations in wind speed, size of turbulence-producing grid, and location of heat source. The nature of the temperature fluctuation field has been studied and the results presented in Technical Note 2710.

HIGH-SPEED AERODYNAMICS

Airfoils

The results of a wind-tunnel investigation performed in the Ames 1- by 3½-foot tunnel to determine the high-speed subsonic characteristics of several NACA 6-series airfoil sections are presented in Technical Note 2670. The more important objectives of this investigation were to provide aerodynamic data for these airfoils, to determine the optimum chordwise position of the point of minimum pressure, and to measure the benefits of reducing the maximum thickness-chord ratio. The results of the investigation indicate that 6-series airfoil sections with the position of minimum pressure near the 40-percent-chord point possess optimum over-all aerodynamic characteristics at high subsonic speeds. Significant improvement in the drag characteristics of these airfoils was found to result from reduction of the maximum thickness. In addition, it was determined that the accompanying reduction in range of lift coefficient for good high-speed section characteristics was much less severe than had been predicted from theoretical analysis.

Supersonic profiles of minimum pressure drag for a given thickness ratio and for a given area have been determined with the use of a nonlinear pressure relation and have been compared with minimum-drag profiles determined by linearized theory. The results show that the profiles are determined with sufficient accuracy by linear theory over the entire supersonic Mach number range and that linear theory appears to be adequate for determining profiles of minimum drag for other auxiliary structural conditions since moderate deviations from the optimum shape have only a small influence on the pressure drag. A comparison of the pressure-drag coefficients for optimum profiles determined by linear and nonlinear theory has been made for the Mach number range from 1.5 to 10.0. In addition, several optimum profiles for a given area have been calculated by both the linear and nonlinear theory. The results are presented in Technical Note 2623.

A velocity-correction formula has been proposed for calculating, from the known Mach number distribution for a diamond-shaped airfoil at a stream Mach number of 1.0, the Mach number distribution on the same airfoil at speeds from a Mach number of about 0.8 to the shock-attachment Mach number. The time required to calculate these additional Mach number distributions is small in comparison with the time required by rigorous methods. The accuracy of the results for stream Mach numbers near 1.0 is of the same order as the accuracy of the known Mach number distribution. Moreover, the results tend to become exact as the stream Mach number is increased toward that for shock attachment. An expression for the rate of change of local Mach number with stream Mach number has been derived and an explicit equation for the drag coefficient as a function of stream Mach number and thickness ratio has been obtained. The results of this work are presented in Technical Note 2527.

Similarity rules for the transonic flow about lifting wings have been derived in Technical Note 2724 by considering the change in the flow field due to angle of attack as a small perturbation to the nonlifting flow field. This approach has the advantage that the effects of angle of attack and airfoil geometry are partially separated. The lift coefficient was found to be proportional to the angle of attack as in other speed ranges. Other results are that the drag due to lift is proportional

to the square of the lift coefficient as in other speed ranges and that the expression for the ratio of lift to drag is very similar to that obtained at supersonic speeds. The maximum value of the lift-drag ratio was found to be approximately inversely proportional to the first power of the wing thickness ratio for cases in which the skin-friction drag is negligible compared with the pressure drag. For cases where the angle of attack is large compared with the thickness ratio, the lift coefficient is proportional to the angle of attack to the two-thirds power. Since the effects of angle of attack and wing geometry are partially separated, the present form of the similarity rules is useful for correlation work. Experimental data indicate that such a correlation will be possible for a lift-coefficient range extending beyond the lift coefficient for maximum lift-drag ratio. Many interesting results may thus be presented in terms of the similarity rules for low lift coefficients. It is shown that the transonic similarity rules are valid at subsonic speeds but are more complicated in that range than the well-known Prandtl-Glauert rules.

Interferometer measurements of the flow fields near two-dimensional wedge and circular-arc sections at zero angle of attack at high-subsonic and low-supersonic velocities have been obtained at the California Institute of Technology in an investigation conducted under contract with the NACA. Both subsonic flow with a region of local supersonic flow and supersonic flow with a detached shock wave have been investigated. Pressure distributions and drag coefficients as functions of Mach number have been obtained and are compared with the theoretical work of Guderley and Yoshihara, Vincenti and Wagoner, and Cole on flow past wedge sections. This work is reported in Technical Note 2560.

Wings and Wing-Body Combinations

Recent calculations of wing characteristics have been made more efficient by the development of reciprocal theorems similar to those long known in electricity and magnetism, optics, elasticity, and many other branches of the physical sciences. These theorems make possible the determination of many important and useful relations between the aerodynamic forces and moments on wings with the same plan forms but having different twist and camber, or executing different motions. A typical theorem states that the lift produced by the deflection of a portion of the wing surface, such as a flap or control surface, is equal to the lift on the corresponding portion of a flat-plate wing in flight in the reverse direction. The range of application of these theorems includes unsteady as well as steady motion and applies to subsonic as well as supersonic flight speeds. This work is reported in Technical Note 2700.

The transonic similarity rules for the pressures, forces, and moments on wings have been found to lead

to an essential improvement in relating experimental wing characteristics at near-sonic speeds. Since the similarity rules may be expressed in various ways, a theoretical investigation was undertaken to ascertain their most advantageous forms. The study, presented in Technical Note 2726, shows that one form is particularly good in that it emphasizes an important difference between aerodynamic characteristics of wings of small and large aspect ratio. The essential parameter for distinguishing the different regimes is the product of the aspect ratio and the cube root of the thickness ratio. When this parameter is large, nonlinear transonic theory must be used to predict the aerodynamic characteristics. When it is small, the lifting properties of the wing may be predicted by linear theory. This behavior has been corroborated by wind-tunnel tests.

A vector study of the partial-differential equation of steady linearized supersonic flow is presented in Technical Note 2641. General expressions which relate the velocity potential in the stream to the conditions in the disturbing surfaces are derived. In this connection, the concept of the finite part of an integral is discussed. A discussion of problems dealing with planar bodies is given and conditions for the solution to be unique are investigated. Problems concerning nonplanar systems are also investigated and methods are derived for the solution of some simple nonplanar bodies. The surface pressure and the damping in roll are found for rolling tails consisting of four, six, and eight rectangular fins for the Mach number range in which the region of interference between adjacent fins does not affect the fin tips.

In Technical Note 2619, a semiempirical profile-correction factor is discussed which enables the estimation of the wave drag due to thickness at supersonic speeds for three-dimensional wings with arbitrary thin airfoil sections at zero lift through use of previously calculated drag coefficients. It is expected that satisfactory estimates can be obtained for many combinations of plan form and profile for which rigorous theoretical drag data are not available by judicious use of the proposed profile correction, especially at those speeds for which the wing leading edge is supersonic.

A method has been developed for selecting the thickness, skin or shell thickness, and size of a supersonic wing for least drag and sufficient bending strength at specified flight conditions, section shape, and wing plan form. The only structural requirement considered in the analysis is that of bending stress, which is assumed to be carried entirely by the skin. An analytical method is presented by means of which the optimum wing dimensions can readily be obtained. This method is presented in Technical Note 2754.

An experimental investigation carried out in the Langley 4- by 4-foot supersonic pressure tunnel resulted

in a series of Schlieren photographs and pressure distributions which showed the effects of transition from an attached to a detached shock at the leading edge of a finite-span 8.2° wedge as the angle of attack was increased from 0° to 11°. These results are reported in Technical Note 2712.

Technical Note 2611 presents the results of an investigation in the Ames 1- by 3-foot supersonic tunnel of the base pressure on wings having an aspect ratio of 3 and various modified double wedge and triangular airfoils. It was found that for turbulent flow the principal variables affecting the base pressure were Mach number and the ratio of boundary-layer thickness to wing trailing-edge thickness. For laminar flow, the principal variable was the ratio of boundary-layer thickness to wing trailing-edge thickness.

A method developed at the Ames Laboratory is presented in Technical Note 2554 for estimating to a reasonable degree of accuracy the interference effects between slender wing-body shapes common to missiles and some high-speed airplanes. Pressure distributions have been calculated for triangular and swept-back plan forms mounted on cylindrical fuselages. The effect of the section profiles on the pressures has also been predicted. An interesting development of the technique also furnishes the effect on the lift of a horizontal tail surface, in the wake of a wing, for cases in which the vortices form a plane sheet or have rolled up into vortex cores.

A theoretical method exact within the framework of linear theory has been developed in Technical Note 2677 that permits a determination of the pressure field of a wing-body combination employing a circular body and a wing with supersonic leading and trailing edges. Detailed calculations have been performed for wing-body combinations with rectangular wings mounted at incidence on bodies at zero angle of attack. It was determined that the loss of lift due to interference could be estimated from the first term of the Fourier series used in the analysis. This fact was used to extend the range of the lift calculation.

At Brown University, under contract to the NACA, a method has been developed for the solution of the nonlinear equations for supersonic conical flow. The procedure is mostly a numerical one based on the method of characteristics and the relaxation process. A procedure for calculating the position of the shock is inherent in the analysis and the method is applicable to any conical flow. The method and an illustration of the flow about a triangular wing with supersonic edges are presented in Technical Note 2651.

Also under NACA sponsorship at Brown University, a basic theory of generalized linearized supersonic conical flow for both inside and outside the Mach cone has been developed and applied to several specific problems including unsteady-flow conditions. A triangular

lifting wing in pitching and rolling with both subsonic and supersonic leading edges was investigated and pressure coefficients were obtained. A family of thin swept-back triangular wings having a symmetrical thickness distribution was also investigated and analytic expressions for wave drag and pressure coefficients were determined. Values of wave drag coefficients were calculated and the results presented graphically. This theory, which stems from a fundamental idea of G. N. Ward, is presented in Technical Note 2667.

Bodies

A theoretical study is presented in Technical Note 2535 of bodies consisting of ogival fore- and afterbodies joined by a circular cylinder having minimum wave drag in axially symmetric supersonic flow. All the bodies studied had the same total length, length of joining cylinder, frontal area and volume. Comparison with related results for bodies of revolution without cylindrical midsections shows that the addition of small amounts of center section has little effect on the drag. From the predicted body shapes, the maximum thickness ratio leading to the least total of wave and friction drag can then be estimated.

A method has been developed for determining the optimum shapes of certain boattail bodies for minimum wave drag at supersonic speeds. The method, presented in Technical Note 2550, is easily generalized to determine minimum-wave-drag profile shapes which have contours that must pass through any prescribed number of points. According to linearized theory, the optimum profiles are found to have infinite slope at the nose but zero radius of curvature so that the bodies appear to have pointed noses, a zero slope at the body base, and no variation of wave drag with Mach number. Although the analysis is concerned with wave drag only, a brief discussion of friction and base drag is also given.

By an adaptation of the slender body theory, expressions have been developed for predicting the lift of bodies, afterbodies, and combinations of bodies. The method is presented in Technical Note 2669 and is illustrated by calculation of the lift of a cone-cylinder body, a cylindrical afterbody of a wing-body combination, and three combinations of bodies.

The calculation of second-order supersonic flow past nonlifting bodies of revolution has been reduced to routine computation with the aid of tabulated functions and standard computing forms. This work has been published in Technical Note 2744.

Research Equipment and Techniques

The great complexity of the method of characteristics in three dimensions has generally limited supersonic nozzle and diffuser design to the two-dimensional and axisymmetric cases. A simple method reported in

Technical Note 2688 has been developed for obtaining three-dimensional unsymmetric supersonic nozzles and inlets from known axisymmetric flows.

Recent research has indicated that three-dimensional supersonic nozzles may become more desirable for high Mach number tunnels than conventional two-dimensional nozzles. In two-dimensional nozzles designed for high Mach numbers the flow is very sensitive to any change of the extremely small dimensions at the minimum section, and the excess growth of boundary layer along the center of the nozzle side plates may also interfere with the design flow. In Technical Note 2711 a method is developed for the design of three-dimensional nozzles utilizing axisymmetric flow. The method is applied to obtain the final coordinates of a nozzle with a Mach number of 10 for which a square test section is specified to reduce the possibility of axisymmetric imperfections at the wall and to provide for the installation of schlieren windows.

Auxiliary boundary conditions are derived in Technical Note 2616 which assure continuity of wall curvature in applying the method of characteristics to the design of two-dimensional symmetrical supersonic nozzles. Fixed nozzles thus designed are less subject to flow imperfections. The technique is particularly valuable in the design of flexible wall nozzles which usually are not capable of sustaining discontinuities in curvature.

An investigation of phenomenon associated with the condensation of air at supersonic Mach numbers is reported in Technical Note 2690. It was found that increasing the ratio of test-section area to the area at the first minimum section produces only a moderate increase in Mach number after the air stream becomes saturated. It was concluded that the most practical method of substantially increasing the test section Mach number is to elevate the reservoir temperature to maintain subsaturated stream conditions. The properties of flow about wedge models in a partially condensed supersonic stream were investigated and effects of condensation on surface pressures were determined.

A theoretical and experimental investigation of the condensation of air in hypersonic wind tunnels has been carried out at the Massachusetts Institute of Technology under contract with the NACA and is reported in Technical Note 2559. The experimental work was done with a hypersonic wind tunnel with a Mach number of approximately 7. Condensation of air was detected and measured by condensation-fog light scattering, static-pressure measurements, and changes in wedge shock angles at degrees of supersaturation considerably lower than those predicted by existing condensation theory. The effects of varying supply pressures and temperatures were measured and it was shown that preheating of the air so that it remained unsaturated or became only slightly supersaturated prevented

the initiation of condensation. The nucleation theory of condensation was modified to take account of a postulated variation of surface tension with decrease in size of the spontaneously formed drops which act as nuclei of condensation. This modification permitted closer prediction of the measured condensation rates.

An instrument has been suggested for the measurement of supersonic flow inclination. The device makes use of the effect discussed in Technical Note 2521 of angle of attack on the meridional velocity profile of the laminar boundary layer on a cone. The theoretical performance of the instrument is discussed and limited experimental results are presented in Technical Note 2723.

Various methods, such as the pitot-static tube and the cone, have been used for determining the ambient or free-stream static pressure in airspeed-measurement systems. Technical Note 2592 considers the problems of determining the free-stream static pressure from the pressures on bodies of revolution. By a simple application of slender-body theory, points are located on a body where only small pressure changes occur with incidence. These points may be then considered as the proper locations for static-pressure orifices. Experimental data obtained during a detailed pressure-distribution investigation of a parabolic body of revolution at a Mach number of 1.59 and a Reynolds number of 3.6×10^6 are then analyzed. The trends predicted are substantiated and slight empirical modifications to the theoretical locations are indicated.

As part of a continuing systematic investigation to study means of improving the accuracy of airspeed measurement systems, six shielded total-pressure tubes were tested at high angles of attack in a wind tunnel (Technical Note 2530). The tubes were tested at several Mach numbers ranging from 0.26 to 0.95; and the effects of inclination of the air stream on the measured pressures were determined for an angle of attack range of $-30°$ to 65°. Results of the tests indicated that curved venturi entries were superior to the conical entry of the standard Kiel design; that the critical angle of a shielded tube could be extended to higher position angles of attack by means of a slant profile; no advantage was to be gained by varying the probe position from the position used in the standard Kiel design; and that the effect of compressibility on the sensitivity of the tubes to inclination was appreciable.

Two procedures of airspeed calibration that are suitable for use in maneuvers at high altitudes and high airspeeds are the accelerometer and radar methods. A comparison of the two methods was made by a calibration of the pitot-static airspeed installation on a jet fighter airplane (Technical Note 2570). The results of the tests indicated that, for vertical plane maneuvers, the accelerometer method may be used as an alternate to the radar method. Although, the accelerometer

method requires airplane instrumentation of fairly high precision, this equipment may be more generally available than the radar equipment.

A stroboscopic schlieren system which automatically synchronizes itself with repetitive aerodynamic phenomena of inconstant frequency has been developed and installed in the Ames 1- by 3½-foot high-speed wind tunnel. This device, discussed in Technical Note 2509, makes possible the visual observation of unsteady air flow about aerodynamic bodies. An additional feature of the instrument provides simulation of continuous slow motion of particular flow features at arbitrarily chosen rates.

An experimental investigation has been conducted in the Ames 10- by 14-inch supersonic wind tunnel to determine the feasibility of using an X-ray densitometer to measure air densities in disturbed flow fields at high supersonic speeds. It was concluded from measurements in conical flow fields that density can be determined with sufficient accuracy at the low densities encountered to establish the instrument as a useful research tool.

An instrument has been developed at the Ames Laboratory that provides an accurate measurement of wind-tunnel Mach number for purposes of tunnel operation and data interpretation. The instrument provides continuous and automatic indications of the quantities determining Mach number, thus permitting considerably more rapid and accurate tunnel operation than heretofore possible.

STABILITY AND CONTROL

Static Stability Investigations

Low-speed tests of typical high-speed airplane models indicate that with regard to static longitudinal stability, a high-wing model with the horizontal tail located below the wing chord plane extended results in acceptable longitudinal stability characteristics. Other tests have shown, however, that for a high-wing model a strong sidewash is produced at the plane of symmetry because of wing-fuselage interference, which reduces the contribution of a conventionally mounted vertical tail to the directional stability. In an attempt to obtain both longitudinal and directional stability over a large angle-of-attack range, tests were made on a configuration having twin vertical fins mounted on a high 45° sweptback wing. The results of this investigation, reported in Technical Note 2534, show that the model was directionally stable throughout the angle-of-attack range, whereas a comparable model with a single fin on the fuselage became directionally unstable at moderate angles of attack. In general, the static longitudinal stability characteristics were not affected by the twin fins.

Studies of wing induced downwash, an important consideration in the design of aircraft with tandem surfaces, have been studied experimentally and analytically. At the Ames Laboratory, a theoretical investigation of the downwash behind low-aspect-ratio plane wings disclosed that significant changes in the downwash field are attributable to large deformation of the trailing vortex sheet. This investigation has been extended to include the missile case where cruciform wing arrangements are utilized. It has been found that the behavior of the vortex sheets behind banked cruciform wings is much more complex and that the downwash field is correspondingly more complicated than that behind plane wings. The results of the first phase of this theoretical analysis along with some experimental data have been published in Technical Note 2605.

An experimental technique for obtaining a physical picture of the flow behind lifting surfaces has been developed wherein the action of a large number of tufts of uniform length attached to a wire grid mounted aft of the wing are photographed from a station downstream of the grid. This procedure yields, with a minimum of labor, an approximate vector plot of the flow field in a plane normal to the airstream. The results of an investigation in the Langley stability tunnel, utilizing the tuft grid technique to determine the downwash characteristics of a rectangular and several triangular wings, are reported in Technical Note 2674.

Studies of Damping Derivatives

The advent of high-speed airplanes of high density has focused attention on certain phases of the dynamic stability problem which were previously unimportant and heretofore neglected. The effect of periodicity of the airplane motion on the effective values of various stability derivatives is one of these factors. A program has been undertaken in the Langley stability tunnel to determine the effects of such variables as frequency and amplitude of motion on the contribution of various airplane components to the stability derivatives. In Technical Note 2657 that phase of the investigation which considers frequency effects on the directional damping and stability of a model undergoing a freely damped yawing motion is covered. The effects of vertical tail aspect ratio and of compressibility as predicted by theory are discussed in relation to experimental stability characteristics obtained by the free oscillation and by the curved flow procedures. The results indicate that, for the low range of frequencies investigated, the vertical tail contribution is relatively independent of oscillation frequency and can be predicted reasonably well by approximate finite aspect ratio unsteady lift theories.

As part of a general program to investigate the effects of changes in various components of the airplane

on the low-speed stability characteristics, an experimental study reported in Technical Note 2587 was made to determine the influence of the wing and fuselage on the vertical tail contribution to the rolling derivatives of a midwing airplane model with 45° sweptback lifting surfaces. The results of the investigation show that the vertical tail contribution to the rolling derivatives can be calculated with good accuracy throughout the angle-of-attack range by available analytical procedures, provided corrections are made for the effects of fuselage and wing sidewash at the tail caused by rolling velocity.

The problem of calculating the stability parameters of an airplane from flight data has been studied at the Ames Laboratory using several common methods for curve fitting. The application of such methods is considered in Technical Note 2622.

The development of the linearized supersonic flow theory has enabled the evaluation of stability derivatives for a variety of wing configurations at supersonic speeds. Fairly complete information is now available for the theoretical stability derivatives of rectangular, triangular, and some sweptback wings. This theory is used in Technical Note 2699 to evaluate derivatives for swept wings for which the wing leading edge and trailing edge are supersonic. Design charts are presented which permit estimation of the pitching-moment coefficient due to angle of attack, and the pitching-moment and lift coefficients due to steady pitching velocity for given values of aspect ratio, taper ratio, Mach number and leading-edge sweepback.

Another theoretical method of determining the supersonic pitching-moment derivatives for delta-wing-body combinations has been developed at the Langley Laboratory. Technical Note 2553 presents solutions for a low-aspect-ratio delta wing and slender body combination and approximate solutions for high-aspect-ratio delta wings and slender body combinations.

Research on Controls

The use of wing planforms incorporating large sweep angles and thin airfoil sections for the purpose of delaying the compressibility effects has resulted in wings having values of maximum lift considerably less than those of conventional unswept wings. This has imposed rather severe limitations on the landing speeds of such aircraft. To add to our knowledge of the characteristics of high-lift devices on such wings, an exploratory test program was conducted under NACA sponsorship in the 9-foot wind tunnel of the Georgia Institute of Technology. Two low-drag, tapered wings sweptback 45° and 60° equipped with full-span split and slotted flaps and three special trailing-edge flaps were investigated. Emphasis was placed on attempts to obtain higher maximum lift coefficients, but the results reported in Technical Note 2468 show no appreciable

gain in $C_{L_{max}}$ for either the split flap or the special flap on the 60° swept wing and only a small increment in $C_{L_{max}}$ on the 45° swept wing. The slotted flap produced the largest lift increments through the angle-of-attack range.

The use of wing sweep has also complicated the problem of determining the speed at which conventional aileron controls become ineffective as a result of wing twisting associated with the control deflection. (This speed is considered the aileron "reversal speed".) Under NACA sponsorship, tests have been conducted in the University of Washington 8- by 12-foot wind tunnel to determine experimentally the effect of wing sweep and elasticity on aileron reversal speeds. Rolling moments due to aileron deflection, damping derivatives in roll, and free rolling angular velocities due to aileron deflection were obtained on the elastic wings with 45° of sweepback and zero degrees of sweepback. The results showed that, when designed for equal stress, the swept wings generally had higher reversal speeds than did the straight wings. It was also shown that inboard ailerons on a swept wing were more effective at high speeds than were control surfaces located at the tips. This work is reported in Technical Note 2563.

Studies have been continued to evaluate various methods of reducing control hinge moments. The effects of various aerodynamic balance shapes on the low-speed control characteristics of a series of unswept and sweptback wings have been studied in the 9-foot wind tunnel of the Georgia Institute of Technology under NACA sponsorship. Lift- and hinge-moment characteristics were obtained for four unswept semispan control surfaces and lift, drag, hinge-moment and pitching-moment characteristics were obtained for two semispan sweptback control surfaces. In Technical Note 2495, measured values of the various parameters are compared with those obtained by application of lifting surface and lifting line theories.

A method of predicting the characteristics of triangular tip-control surfaces at supersonic speeds for which the Mach lines lie behind the trailing edges has been developed using linearized theory. The results of this study are presented in Technical Note 2715 in the form of equations and charts for the evaluation of lift, pitching-moment, and hinge-moment parameters for the basic configurations and tabulated calculations for configurations having unequally swept wing and flap trailing edges.

Investigation of Flying Qualities

One of the methods being utilized to reduce the large control forces which are becoming more prevalent with high-speed aircraft is through the use of a booster power-control system incorporating a mechanical device to provide the pilot with artificial stick force (feel). A flight investigation of this type of system

installed in a bomber airplane has been made at the Langley Laboratory to determine the design features that should be incorporated in feel devices in order to obtain satisfactory handling qualities. The feel device consisted of a centering spring which restrained the control stick through a linkage that changed as a function of dynamic pressure. Provisions were made for trimming and for manual adjustment of the force gradient. The system was designed to approximate the control-force characteristics that would result with a conventional elevator control with linear hinge-moment characteristics. The test results reported in Technical Note 2496 indicate that the overall performance of the feel device was satisfactory. The original control system of the test airplane exhibited certain undesirable stick-force characteristics resulting from nonlinear hinge-moment variations. These characteristics were improved or corrected by the feel device. The device made possible smoother landings with less pilot effort and improved the airplane's stick-force characteristics in maneuvers.

Numerous devices have been described in literature over a number of years for providing a stall warning for aircraft. This literature is scattered and some is generally unavailable. Thus, a summary of these data was prepared. In the summary, published as Technical Note 2676, the principles involved in the operation of several types of stall-warning devices are described, and the conditions under which operating difficulty may be experienced are pointed out.

The present trend toward the use of light aircraft in farming and ranching activities and the indication that nearness to centers of population is important to the success of airport operation, make it increasingly desirable that the personal-owner-type airplane be able to take off and land in short distances using poorly prepared airfield surfaces. Technical Note 2404 reports on the results of an NACA sponsored investigation at the Texas A and M Research Foundation, aimed at improving take-off performance through the use of flaps. The optimum lift coefficient for takeoff for airplanes having loadings representative of personal aircraft and flying from field surfaces encountered in personal aircraft operation, are analyzed. Power loading, span loading, aspect ratio, and drag coefficient were varied sufficiently to determine the effect of these variables on take-off performance. Existing high-lift and control device data were studied and compared in order to determine which combinations of such devices appear to offer the most suitable arrangement for aircraft of a private-owner type. The results indicate that considerable improvement in take-off performance of light airplanes is possible by the use of suitable high-lift flaps.

Automatic Control and Stabilization

The problem of designing control systems that are self regulating to the extent that desired maximum values of airplane normal acceleration cannot be exceeded by pilots has received special attention. In Technical Note 2574, possible methods of operation of acceleration restrictors are discussed, and a theoretical analysis is made of some simple devices. The acceleration restrictors analyzed work on the principle of stopping the upward motion of the elevator when the signal from the acceleration sensing device reaches a certain value. Calculations were made for a representative fighter airplane and a representative transport airplane over a range of center-of-gravity positions for sea level and altitude operation.

An investigation to determine how well the longitudinal dynamic stability of an autopilot-aircraft combination can be predicted from the separately measured characteristics of the autopilot and of the aircraft is reported in Technical Note 2578. The dynamic longitudinal stability of the airplane with autopilot was predicted by combining the transfer functions of the autopilot as obtained from ground tests with those of the airplane measured in flight to obtain the open and closed loop frequency responses and transient responses for the combination. These predicted responses were then compared with measured flight frequency and transient responses for three airspeeds and various autopilot settings of displacement and rate of displacement feedback. The analysis procedures were based upon linear methods. Flight test data were in good agreement with linearized analysis when system elements were operated within their linear ranges.

For various reasons, automatic guidance systems of aircraft often contain elements that have nonlinear response characteristics during certain phases of their operation. Depending upon the degree of these nonlinearities, the system may be amenable to a linear analysis or it may be necessary to consider the system as nonlinear. In Technical Note 2707, the nonlinear response characteristics of an electrohydraulic servo system are considered. These characteristics were successfully simulated and studied through the use of an electronic analog computer. In this study, it was found necessary to take into account the nonlinear amplifier characteristics and also the accumulative effect of servo system time lags to simulate satisfactorily the servo system.

A great deal of interest has recently been shown in automatic stabilization devices as a means of improving the damping of the lateral oscillation of aircraft designed for transonic and supersonic flight. The results of a theoretical study of the effect of auxiliary damping devices on the lateral stability and controllability of

a high-speed aircraft are reported in Technical Note 2565. The systems investigated included stabilization devices which deflect the rudder or an auxiliary surface proportional to the yawing velocity or rolling acceleration and one which deflects both aileron and rudder proportional to the rolling velocity. An idealized control system without phase lag was assumed. The results indicate that each of the assumed stabilization systems is capable of improving the damping of the lateral oscillations of the assumed aircraft. However, the system which deflected the rudder proportional to yawing velocity necessitated increased pedal forces in steady turns and the systems which deflected the rudder or rudder and ailerons proportional to rolling velocity required unnatural rudder deflections to maintain zero sideslip subsequent to applied rolling moments. The system which deflected the rudder proportional to rolling acceleration introduced adverse yaw subsequent to applied yawing or rolling moments.

A graphical method of determining the amplitude ratio and phase angle of transfer functions from the standpoint of facilitating the analysis of complicated dynamic systems is presented in Technical Note 2522. This method does not require the factoring of polynomials and can be adapted to the use of templates. An example is given in which the frequency response of an automatically controlled aircraft is obtained.

INTERNAL FLOW

Air Induction Systems

In the selection of an air induction system for jet-propelled aircraft, it is necessary to know the optimum compromise between external drag, mass flow per unit inlet area, and pressure recovery. Exact knowledge of the complex inter-relation of these factors is particularly essential because the air-induction system may be a large potential source of drag in modern aircraft designs. To facilitate the selection of optimum arrangements, a study reported in Technical Note 2697 was made to outline a method for the evaluation of various air-induction systems when combined with arbitrary jet engines. Charts based on the air handling qualities of induction systems and the component characteristics of engines are presented to permit rapid evaluation of air-induction systems over a range of flight speeds up to a Mach number of 3.0.

The correct consideration of drag and thrust forces acting on a turbojet engine installation is a problem of major importance in the design and performance estimation of new aircraft. Although a basically simple problem, fundamental analysis of the forces may become obscured by the use of conventional definitions for these forces. A study of the forces acting on a turbojet engine installation (inlet, engine, exit) has been made and the results presented at the annual summer meeting

of the Institute of the Aeronautical Sciences and published in "Aeronautical Engineering Review," October 1951. In this paper, conventional definitions have been related to the fundamental force concepts involved for both subsonic and supersonic applications through a summary of existing analyses.

Diffusers and Ducts

A preliminary analytical and experimental study of the instability of flow from two ducts discharging into a common duct has been conducted at Harvard University and the results reported in Technical Note 2417. Analyses were made by assuming potential flow conditions and turbulent mixing. Qualitative considerations indicated that self-excited forces may arise to account for observed instabilities. The nature of the flow (stable, oscillatory, asymmetric, etc.) and variations of the type of flow with duct configuration were studied experimentally using a two-dimensional water table.

An experimental investigation has been conducted at the Langley Laboratory to determine the performance of a 90° cascade diffusing vane for five inlet boundary-layer-thickness conditions. Tests were made at Mach numbers up to 0.41 and at Reynolds numbers, based on the cascade airfoil chord, of 330,000 to 950,000. The results reported in Technical Note 2668 indicated that for a vaned bend a limited amount of diffusion can be obtained without appreciable energy losses. The vaned bend has the advantage of being much shorter than the usual diffuser-bend combinations.

An analytical study of two-dimensional non-viscous and viscous compressible flow through a system of equidistant blades has been conducted at the Polytechnic Institute of Brooklyn under the sponsorship of the NACA, and the results reported in Technical Note 2718. Non-viscous flow through blade systems of equidistant spacing and of identical shape is considered. A numerical example is given for a system of symmetric blades which produce a 90° deflection of a uniform flow. Viscous flow through a grid system is treated by the introduction of a velocity, velocity gradient, pressure, and force field of uniformity across the blades.

ROTARY WING AIRCRAFT

Some effects of varying the damping in pitch and roll on the flying qualities of a small single-rotor helicopter are reported in Technical Note 2459. Flight-test measurements and pilots' opinions of the longitudinal flying qualities and lateral control characteristics of a small single-rotor helicopter are presented. In these tests the damping of the helicopter in pitch and roll was varied by means of a rate-sensitive automatic-control device from the amount present in the helicopter with the device inoperative to nearly three times that amount. Longitudinal stability and control characteristics which were unsatisfactory with the device inoperative were

improved by increasing the damping of the helicopter, and were judged to be satisfactory when the damping was approximately doubled by the device. The low rate of roll associated with the largest amount of damping tested was adequate for normal flying.

Since the ability to operate under instrument flight conditions will materially extend the usefulness of the helicopter, the Langley Laboratory has undertaken a flight investigation to determine what flying qualities and what flight instruments are necessary for satisfactory all-weather operation. Some initial results of this program are reported in Technical Note 2721, wherein it was concluded that, although existing longitudinal-flying-qualities requirements for helicopters are adequate for instrument flight at speeds near cruising, both the flying qualities and pilot's instruments will require improvement before satisfactory instrument flight is possible from hovering to maximum speed.

One approach to the problem of providing more suitable instruments for helicopter blind flying is to combine on a single indicator information that is usually obtained from several different instruments. A commercially available flight indicator which combines heading, altitude, bank angle, and pitch information was modified for helicopter use and flight-tested under simulated instrument conditions. The results, presented in Technical Note 2761, indicate that use of the combined-signal indicator for helicopter blind flying enabled the pilot to maintain a more accurate flight path and required less concentration than use of conventional instruments alone.

Although standard rotor theory has proven adequate for predicting the performance of present day helicopters, certain of the assumptions used in the development of the standard theory limit the usefulness of the theory in the study of the characteristics of high performance helicopters. The development of theories adequate for high speed helicopters are presented in Technical Note 2656 prepared by the Georgia Institute of Technology under NACA sponsorship, and in Technical Note 2665 by the Langley Laboratory. Neither theory is limited to the flight conditions wherein the rotor-blade-section inflow angles are small and wherein there is little or no reversed flow over the rotor disc as in the case of the standard theory. Although both theories are in agreement with existing experimental data and standard theory on flapping rotors at low tip speed ratios, the theory developed by Langley appears to be more applicable to the study of flapping rotors and the Georgia Tech theory more applicable to the study of rigid rotors because of the system of axes chosen.

Methods are available for estimating the mean value of induced velocity through a helicopter rotor in hovering and steady autorotation. No theory is available, however, for treating the flow during the transition from hovering to autorotation and the development of a

rigorous theory would be extremely difficult because of the unsteady flows which predominate in this regime of flight. Technical Note 1907 assumed an exponential variation of induced velocity during the transition; however, there was at the time of publication of this report insufficient experimental data to confirm the assumption. Princeton University, under NACA sponsorship, undertook an investigation of the transition from hovering to steady, vertical autorotation of several rotor models with the object of determining the validity of the previously assumed exponential variation of induced velocity. The results of this investigation presented in Technical Note 2648 indicate that the effective induced velocity during transition often differs greatly from the previously assumed variation.

Recent flight data on the autorotational characteristics of a helicopter were in serious disagreement with existing wind tunnel results and Glauert's empirical induced velocity relations. In view of this, the Georgia Institute of Technology, under NACA sponsorship, undertook a wind-tunnel study of the induced velocity, thrust and rate of descent of several helicopter rotor models. The objects of the program included an evaluation of the validity of Glauert's empirical relations, a determination of the sources of error in previous wind-tunnel studies of the induced velocity through autorotating rotors, an indication of the effects of blade taper and twist on vertical descent characteristics, and flow visualization with smoke and tufts. The results of the investigation, presented in Technical Note 2474, indicate considerably lower mean induced velocities in hovering and in small rates of descent, and considerably higher mean induced velocities at high rates of descent than would be predicted by Glauert. The wind tunnel results are in fair agreement with flight experience. The effects of both blade twist and taper are also discussed.

Statistical information concerning the flight loads and associated operating conditions of a helicopter engaged in air-mail operations has been obtained. An analysis of the normal accelerations and operating conditions encountered in 253 hours of flying time is presented in Technical Note 2714. The results indicate that for this type of operation the loads developed in routine takeoff and landing-descent maneuvers are often greater than the maximum loads encountered en route.

Existing theoretical methods of calculating the loading and bending moments on helicopter rotor blades are known to be in error because of certain simplifying assumptions made in the development of the theory. The Massachusetts Institute of Technology, under NACA sponsorship, has developed a wind-tunnel technique for determining blade bending moments and has evaluated the accuracy of existing methods of blade bending moment calculations for a flapping rotor. Also, existing

theory for application to fixed-at-root blades has been modified. The results of the investigation are reported in Technical Note 2626 and show that for both the fixed- and hinged-at-root blades the experimental data are in fair agreement with theory; however, the many discrepancies between theory and experiment are pointed out and, where possible, explained.

AIRCRAFT PROPELLERS

A study of the effects of wing sweep in varying the forces on propeller blades as they rotate through 360° has been completed and arranged in a form to demonstrate these effects readily. This study, together with the method of predicting the independent effects of a wing-fuselage and nacelle, has been experimentally verified by powered model wind-tunnel tests reported in Technical Note 2795. The experimental study of downwash included 40° swept wings of aspect ratio 7 and 10 with nacelles mounted on the wing and on struts extending from the wing, at various wing span stations. All these data make available to the designer a means of obtaining analytically a good estimate of once-per-revolution propeller exciting forces, and for a repre-

sentative group of designs, a detailed description of the flow field in the propeller plane.

SEAPLANES

The NACA has conducted several investigations at the Langley Laboratory to provide basic and design data for water based airplane configurations as well as for seaplane components. Also, the NACA has sponsored an investigation of the hydrodynamic characteristics of a series of hull models suitable for small flying boats and amphibians at the Stevens Institute of Technology. In this investigation, reported in Technical Note 2503, the hydrodynamic resistance and main spray characteristics were determined for a group of hulls consisting of a basic hull having simple lines, and of variations in this design in which the beam, sternpost angle, and afterbody length were altered. Three of the most promising hulls were tested for landing and porpoising characteristics. The results showed that it is possible to design a hull with simple lines suitable for small flying boats or amphibians. The results also indicated that refining the hull lines would improve the hydrodynamic characteristics only slightly at the expense of more complicated construction features.

POWER PLANTS FOR AIRCRAFT

Propulsion research under way at the NACA is aimed towards meeting the needs of the accelerated defense program which calls for production by industry of aircraft engines at a constantly accelerating rate during the next few years. This research has been planned in the light of the needs for (a), reduction in the time to place into service use those engines currently in the initial sea-level qualification test stage at manufacturers' plants; (b), rapid research and development on advanced engines incorporating new basic research ideas.

The NACA has not only the responsibility of providing the fundamental research ideas and information leading to future advances in engine performance and operation, but also has, by virtue of its unique facilities and at the request of the military services been instrumental in determining that these fundamental research contributions have been satisfactorily applied to specific engines under contract production for military use. The gas turbine engine is a complicated and delicate piece of machinery and is sensitive to the environment in which it is operated. When it is being operated in the upper atmospheres (40,000, 50,000 and 60,000 feet), where the temperatures can go as low as $-100°$ F., it performs differently than it does in a sea-level test stand.

The NACA Lewis Laboratory is uniquely equipped with facilities where full-scale prototype and production engines may be operated and their performance and operational characteristics explored under the conditions experienced in actual high altitude and supersonic flight. The operation of actual prototype gas turbine engines in altitude facilities not only provides evaluation and further development of the application of fundamental research contributions to actual engines, but also serves to discover and solve many difficulties of operation that were not previously known or anticipated. Propulsion research conducted by the NACA has contributed greatly to the technical excellence of our country's current engines and reduced the need for extremely costly, hazardous, and time-consuming engine research and development by means of flight testing.

AIRCRAFT FUELS RESEARCH

During 1952 aircraft fuel research was directed toward refinement of current jet-fuel specifications. The major NACA contribution to this research was the investigation of carbon deposition in typical turbojet engines; however, some attention was given to the physical properties of fuels that are pertinent to the problem of fuel handling in the aircraft environment.

The program on future fuels was continued and considerable progress has been made in studies of pure hydrocarbons of interest as fuel components. The hydrocarbons studied promise more energy release per unit volume and have desirable flammability characteristics such as high flame speed, wide stability limits, and low ignition energies.

Synthesis and Analysis

The synthesis and the purification of 40 high-density hydrocarbons were reported during the past year. These compounds are dicyclic types and because of the high density provide more energy per unit volume than marketed fuels. This high energy content makes these fuels attractive for high-speed volume-limited aircraft. In order to provide a complete evaluation of the nature of these fuels, many of the physical properties have been determined. (Technical Notes 2430 and 2557.)

An investigation was also conducted on a series of cyclopropylalkenes in order to determine the effect of molecular structure on physical and chemical properties of pure hydrocarbons. Ten compounds in this series were prepared, and melting points, boiling points, refractive indices, densities, and heats of combustion were determined.

As part of the general research program on pure hydrocarbons, efforts have been made to correlate physical properties with molecular structure. The trends established by these correlations are quite useful in planning future synthesis projects since the data clearly indicate which classes of hydrocarbons show the greatest promise as potential jet fuels. Correlations of properties with molecular structure for three series of hydrocarbons were completed during the year and are reported in Technical Note 2419.

In the field of analytical chemistry, a method has been developed for the determination of methyl (CH_3), methylene (CH_2), and aromatic CH groups by near-infrared absorption spectroscopy. This method is applicable to hydrocarbons of high molecular weight and may be applied to commercial products such as lubricating oils, paraffin wax, and polystyrene.

Fuels Performance Evaluation

Many of the pure hydrocarbons synthesized for research investigations are made in sufficient quantity to permit evaluation of combustion properties. In labora-

tory apparatus, measurements were made of flame speeds, flammability limits, ignition energies, and ignition temperatures. The most recent study of this type was an extension of flame-speed measurements to include 17 additional compounds. At this writing, flame speeds have been determined for 54 pure hydrocarbons. The results of the most recent investigations indicate that cyclic compounds have greater flame speeds than comparable straight-chain hydrocarbons.

In regard to the application of current fuels to aircraft, one project has been completed which is essentially a fuel-handling problem arising from the behavior of dissolved water in conventional aircraft fuel systems. The solubility of water in hydrocarbon fuels is of interest in that most fuels are substantially saturated with water at some stage during processing and storage. This water can become troublesome in applications where fuel is subjected to low temperature and the water freezes. Ice crystals thus formed block the filters in the aircraft fuel system.

A literature survey was made to compile data on the solubility of water in pure hydrocarbons and in hydrocarbon mixtures. An attempt was made to correlate these data in such a way that a reasonably accurate prediction could be made of the solubility of water in any hydrocarbon fuel at any temperature. An equation was developed to permit this prediction.

A problem encountered in the operation of turbojet engines with current, wide-boiling-range hydrocarbon fuels is combustion-chamber carbon deposition. The formation of carbon on fuel injectors causes alterations in fuel-spray pattern with possible effects on combustor performance; similar effects on performance can result from the deposition of carbon on primary air-entry ports. Altitude starting may be impaired by the deposition of carbon on spark-plug electrodes. Finally, the deposition of carbon on the high-temperature areas of combustor liners promotes liner cracking and warping from excessive temperature gradients and variations in thermal expansion rates.

Carbon deposition is dependent upon two factors; combustor design and choice of fuel. While carbon deposition may be reduced considerably in future combustor designs, the modification necessary may result in a deterioration of other performance characteristics. With respect to the fuel properties, however, changes which alleviate the carbon-deposition problem also promote, in general, increased over-all performance. Therefore, if limits in fuel characteristics can be selected which will adequately control carbon deposition without an excessive compromise in fuel availability, the inclusion of such limits in turbojet-engine-fuel specifications would be desirable.

Additional studies of carbon deposition have been conducted in which the effects of fuel properties on combustion chamber deposits were evaluated in single tubular fuel-atomizing and fuel-vaporizing combustors. The effects of sulfur, gum, and olefin content were also investigated.

Effect of Fuel Density and Heating Values on Ram-Jet Missiles

The analytical investigation of the effects of fuel density and heating value on the cruise range of a ram-jet airplane has been reported. In order to isolate fuel-property effects as much as possible, the optimum compromise between weight and efficiency was approximated for various wing, engine, and fuselage combinations. Fuel-property effects are presented for the optimum designs thus obtained. The results of the study indicate which fuels would be most advantageous for a specific mission.

COMBUSTION RESEARCH

The primary objective of combustion research is to determine how to obtain optimum combustion of fuel and air in the space allotted in the engine. In order to achieve this objective, it is necessary to first understand the fundamental mechanism of combustion and second to understand the transitions that must be made for the application of these fundamental mechanisms to the actual engine. This approach necessarily involves research in simplified laboratory apparatus and in full-scale engine combustion chambers and the information so obtained provides the design criteria upon which development of future engines may be based.

Fundamentals of Combustion

One of the important processes in a jet-engine combustor is the propagation of flame into the unburned fuel-air mixture. A better understanding of the physical and chemical nature of this process may be gained by a study of laminar flame speeds. An analysis of available data indicated that the burning velocity of a fuel-air mixture is related to the equilibrium flame temperature and the relative diffusion concentration of atoms and free radicals ahead of the flame. Specific rate constants calculated from the Tanford and Pease equation by use of the calculated atom and free-radical concentrations were nearly the same for all hydrocarbons studied. The results indicate that the maximum flame velocities of hydrocarbon-air mixtures are consistent with an active-particle mechanism of flame propagation. These results have been used to calculate equilibrium flame temperatures and equilibrium free radical concentrations for pentane, ethylene, and propyne over the total flammability range in air.

Experimental studies of flame speed have been extended to include an evaluation of the effect of initial temperature on flame speed. Data for methane-air, propane-air, and ethylene-air flames over the temperature

range from room temperature to 344° C were published in Technical Note 2624.

The process of quenching is important to the behavior of flames because this process may control flame stabilization, pressure limits of flammability, and the efficiency of combustion in the region of cold surfaces. An approximate equation has been derived for quenching distance based on the effect of the destruction of atoms and free radicals by a surface, on the chemical reaction, and on flame propagation.

For several years, much of the flame propagation research has been conducted in a tube apparatus, in which it has been found impossible to measure flame speeds in excess of 70 centimeters per second. This difficulty was attributed to turbulence in the unburned mixture ahead of the flame; consequently, it was felt that reduction in the size of the tube would eliminate the problem and permit measurements of certain high flame speed materials. Orientation tests were made in the rebuilt apparatus with acetylene-air mixtures. The results indicated the maximum fundamental flame speed of these mixtures to be about 141 centimeters per second, a value in good agreement with Bunsen burner results.

Data for gaseous hydrocarbon fuels have already shown the marked effect of the percentage of oxygen in oxygen-nitrogen mixtures on minimum ignition energy, blow-off and flash-back limit, quenching distance, and flame speed. Data of this type should give clues as to the importance of reaction kinetics in flame propagation and should yield further information on what the over-all mechanism of flame propagation might be. Furthermore, such data for liquid fuels would be of special interest because of their value in the interpretation of the combustion process in aircraft engines. An investigation is under way in which some of the combustion properties of isooctane-oxygen-nitrogen mixtures are being studied. The experimental values of maximum flame speed have been compared with the values predicted by theories of flame propagation based on either a thermal or a diffusion mechanism. The results of this investigation are presented in Technical Note 2680.

These studies have been extended to determine the change in the pressure limits of flame propagation with tube diameter for various isooctane-oxygen-nitrogen mixtures. The effects of oxygen concentration upon the pressure limits and concentration limits of flame propagation were also investigated.

It has been suggested that low-pressure limits of inflammability may be governed by quenching effects. Work was undertaken to obtain suitable data with which to investigate this possibility and for later use in gaining a better understanding of the process by which flame propagation is limited by tube diameter. In addition, it was desired to learn more about the rela-

tion of the critical diameter for flame propagation to other combustion properties, particularly rate of flame propagation and minimum ignition energy.

Research was undertaken to determine whether smoke added to a combustible mixture from an outside source could be burned in the reaction zone of a flame. The question of whether smoke will burn completely in the reaction zone of a flame has an important bearing on combustion-chamber research aimed at preventing smoking. Varying amounts of smoke, both in the form of concentrated filaments and dilute homogeneous mixtures with the combustible, were burned in diffusion flames of ethylene and in Bunsen flames of ethylene-air mixtures. Stable flames of both types were found capable of burning large amounts of carbon smoke if the smoke was finely divided.

Combustion-Chamber Research

The design of high-output combustors for jet-propelled aircraft requires an accurate knowledge of liquid vaporization rates. In jet engines, the fuel is frequently injected as liquid droplets at a point upstream of the combustion zone, and the concentration of vaporized fuel in the fuel-air stream entering this zone is determined by the rate of evaporation of the droplets. In order to determine this evaporation rate, a study was made of droplets vaporizing under conditions similar to those encountered in aircraft combustion systems (Technical Note 2368).

As a part of the research concerned with ignition and combustion of fuel-air mixtures, the parameters which may influence the energy required for a spark to ignite homogeneous fuel-air mixtures are being investigated. Research has been conducted to determine the effect of the electrode parameters of spacing, configuration, and material on the energy required for ignition of a flowing propane-air mixture. The data have been used to indicate the energy distribution along the spark length and to confirm previous observations concerning the effect of spark duration on ignition energy requirements.

A photographic pyrometer has been designed to determine the apparent surface temperatures in a ram-jet combustion chamber, where the immediate range of interest is 2,000° to 3,200° F., where it is necessary to record several temperatures instantaneously, and where thermoelectric pyrometry is impractical or impossible. The photographic pyrometer indicates apparent surface temperatures by photographing hot surfaces and correlating the variable density of the photographic negative with the apparent surface temperature.

LUBRICATION AND WEAR

Fundamentals of Friction and Wear

Experimental studies by numerous investigators have established the concept that the effectiveness of extreme-

pressure lubricant additives is dependent upon a chemical reaction between the additives and the lubricated surfaces to produce a surface film having the desired lubricating properties. Previous investigations have established the minimum film thickness of sulfide on copper. To provide similar information for sulfide on steel, an investigation was conducted to study chemically the formation of sulfide films on steel and to establish the minimum film thickness necessary (Technical Note 2460). The calculated rate of film formation on steel in a solution of 0.5 percent free sulfur in cetane was approximately 1.8 x 10⁵ Angstrom units per second in the temperature range from 1,000 to 1,100° F. Static friction data indicated that dry film thicknesses of 5000 Angstrom units or greater were necessary to prevent surface welding completely. Welding was appreciably reduced, however, with film thicknesses as low as 3400 Angstrom units.

The extreme corrosive nature of most liquid metals proposed for use at elevated temperatures in aircraft powerplants introduces many critical design problems; for example, obtaining satisfactory materials for sliding surfaces, such as pump bearings. Accordingly, an investigation was conducted to determine the friction and surface damage characteristics in air of several materials that are resistant to corrosion by liquid metals. The materials tested included steel, stainless steel, Monel, nickel, Inconel, Nichrome, zirconium, and tungsten carbide. Appreciable surface damage was evident for all materials tested except tungsten carbide.

One of the principle sources of failure in rolling-contact bearings of aircraft turbine engines has been the cages. These failures are generally lubrication failures and occur in the cage locating surfaces. One means of reducing the severity of this problem is to make the cages of materials which have inherent "anti-weld" characteristics under marginal conditions of lubrication. Accordingly, the wear and sliding friction properties of a number of nickel alloys for use below 600° F. operating against hardening SAE 52100 steel were studied (Technical Note 2758). On the basis of these tests Ni-Resist 3, modified "H" Monel, and Invar were the best materials studied, although they did not perform as well as the nodular iron studied previously.

This investigation was continued with the objective of studying a number of materials for use above 600° F. (Technical Note 2759). This included cast beryllium, nickel, heat-treated beryllium-nickel, cast Inconel, Nimonic 80, Inconel X, Refractalloy 26, and Discaloy. The cast Inconel performed very well in these experiments and compares favorably with nodular iron. Nimonic 80 also showed promise as a cage material.

Bearing Research

In an effort to provide a practical means of estimating rolling contact bearing temperature changes, due to a change in such operating variables as oil flow, oil inlet temperature, oil jet diameter, and DN values, a generalized equation has been derived, based on a series of previous investigations (Technical Note 2420). It appears possible to predict inner-race or outer-race bearing temperatures from a single curve regardless of whether speed, load, oil flow, oil inlet temperature, oil inlet viscosity as affected by oil inlet temperature, oil jet diameter, or any combination of these parameters is varied.

In order to determine whether the relationships derived in Technical Note 2420 would apply to a bearing operating in an actual engine, an investigation was conducted to compare the operating characteristics of a laboratory test bearing and an aircraft jet engine roller bearing. The relationships appear to be valid even though the test engine bearing conditions were sufficiently different from the laboratory test bearing conditions that a number of temperature reversals were noted.

The influence of oil viscosity on the effectiveness of cooling and lubricating high-speed rolling-contact bearings is of significance in turbojet and turbo-prop engine design. Not only must the bearing be lubricated, but a large portion of the bearing heat must be removed by the lubricant. An investigation was conducted to study the effects of oil viscosity on the operating characteristics of high speed roller bearings (Technical Note 2636). In particular, the effects of oil viscosity, oil flow, and oil inlet temperature on the bearing temperature and power rejected to the oil were obtained. In the viscosity range investigated, the bearing temperatures increased with increasing oil viscosity at a constant DN load and oil flow.

Cornell University, under the sponsorship of the NACA, has been conducting an investigation of the effect of misalinement on plain bearings for the past 3 years. Recently, information has become available on a program having the objective of studying the effect of misalining couples upon oil film pressure distribution in a journal bearing (Technical Note 2507). The most important effect noted was the relatively small displacement of the load from the center of the bearing (16 percent of the bearing length) to produce a large disturbance in the oil film pressure.

COMPRESSOR AND TURBINE RESEARCH

Compressor Research

Research on the compressor component of the turbojet engine is being directed toward the development of compact, light, efficient machines having high pressure ratios per unit length and high air flows. This research consists of theoretical study of basic phenomena and the experimental evaluation of compressors

for the development and evaluation of design procedures for industry.

Studies of the basic effects of viscosity have been made to increase the understanding of the important but heretofore neglected three-dimensional effects in turbomachinery. The development of the laminar boundary layer over a flat plate in a flow having concentric circular streamlines was analyzed and both the boundary-layer thickness and the flow deflection at the plate surface were found to increase as the Mach number of the main flow increased (Technical Note 2658). A theoretical study of two-dimensional shear flow in a 90° elbow was made and solutions were obtained for two types of velocity distribution induced at the elbow inlet (Technical Note 2736).

A mathematical technique has been developed and extensively checked for designing blades of axial- or mixed-flow turbomachines. A flow solution was first obtained on a surface roughly parallel to and midway between two blades and then extended toward the blade surfaces by power series expansions using values of the unknown derivatives from a solution obtained on a complementary surface (Technical Note 2604). The technique was expanded to a surface of revolution by two methods, both of which assumed the flow confined to the surface. Relaxation techniques were used in Technical Note 2455 to obtain a solution while a cyclic series expansion method was used in Technical Note 2702. It was found that discrepancies obtained in the blade shape could be eliminated by adjusting the initial assumptions and repeating the calculations. The technique was further extended to supersonic flows by setting up the equations in characteristic variables (Technical Note 2492). Computational studies on the parallel, midchannel surface were made in Technical Notes 2750 and 2749. The former employed a matrix method and was done on IBM and UNIVAC. The latter employed a relaxation technique and was the more time-consuming. A method which accounts for the three-dimensionality of the supersonic flow field in a turbomachine based upon a mathematical theory for the type of equation involved is presented in Technical Note 2705. It requires the velocity to be prescribed on a suitable surface and uses numerical methods to obtain a solution.

To obtain an independent measure of the accuracy of approximate compressible flow solutions, four necessary conditions for steady, irrotational, compressible flow were obtained. An application to typical compressor cascades indicated that an approximation based on the linear pressure-volume relation is considerably more accurate than the incompressible or Prandtl-Glauert approximations (Technical Note 2501).

Studies have been conducted in two-dimensional, static cascades to facilitate the development of efficient

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flow passages in turbomachines. The effect of Mach number on the aerodynamic parameters of a typical compressor blade was investigated and a correlation between theory and data from solid wall cascades was found by using the contraction coefficient. Various compressibility correction methods were compared with experimental results and a method which most nearly approximated the coefficient of lift was presented (Technical Note 2649). General flow channel design techniques have been developed using relaxation methods (Technical Note 2593) and Green's function (Technical Note 2595). The application of these techniques to the design and experimental investigation of a 90° impulse cascade of compressor or turbine blades has shown that blades can be designed for prescribed blade surface velocities, negligible boundary-layer separation, and good efficiency (Technical Note 2652).

The research on multistage compressors has consisted of investigations into surge limitations, stage matching, off-design performance and viscous effects. A review and survey of the centrifugal and axial-flow compressor research work done by the NACA in experimentally determining the nature of flow during surge and the general explanations of the surge phenomena that have resulted from this work have been presented. A discussion of the multistage axial-flow compressor showed several possible means of varying the surge limit and avoiding surge problems by improving the compressor efficiency at part speed.*

The design of a 10-stage axial-flow compressor employing a symmetrical diagram, constant total enthalpy at all radii, and a stage pressure ratio of 1.2 was carried out. An analysis of the effects of the principal design variables was made in order to estimate the upper limit of stage pressure ratio for subsonic blade sections. The study indicated that the assumption of 85 percent adiabatic efficiency, 1.30 average stage pressure ratio, and an equivalent weight flow of 26 pounds per second per square foot of frontal area is reasonable and obtainable using practical design limitations (Technical Note 2589).

As part of the general program to develop efficient high-pressure-ratio compressors, the Langley Cascade Aerodynamics Section has evolved a method for the preliminary design calculation of high-pressure-ratio multiple-stage axial-flow compressors using the solid-body inducer-type design (Technical Note 2598). Compressors of this type have an inducer first stage which sets up a prescribed total-temperature distribution so that the inlet axial velocity to the second stage is radially constant. The remaining stages have radially constant power input, average tangential velocity proportional to the radius, and radially constant rotor inlet

*See Bullock and Finger paper in "Other Technical Papers by Staff Members," page 59.

axial velocities equal to the inlet axial velocity of the compressor. A chart which facilitates preliminary design calculations for any solid-body inducer-type design is presented.

Research on the impellers and diffusers of centrifugal compressors has been carried forward with theoretical analyses and with experimental units for establishing the merits of the theoretical results. Analytical studies of impellers were completed in which flow variations from hub to shroud and from blade to blade were investigated. In the hub-to-shroud studies, methods of analyzing impellers of arbitrary design were developed and the effects of inducer vane curvature on the flow in a typical centrifugal impeller were evaluated (Technical Note 2464). Similarly a method of analysis was developed for the flow from blade to blade in turbomachines having an arbitrary blade shape. The effect of varying flow rates and blade spacings was studied in an impeller having an arbitrary hub-shroud contour (Technical Note 2654).

An analysis method and a design procedure were developed for the flow in vaneless diffusers having arbitrary profiles in the axial-radial plane. From numerical examples, it was concluded that friction losses in most vaneless diffusers are significant and result from the unusually large ratios of wetted surface to flow area and that vaneless diffuser efficiency can be improved by increasing flow rates for a given impeller tip radius (Technical Note 2610).

A one-dimensional flow analysis of a radial inlet-type impeller was conducted to provide an insight into the channel flow characteristics under the influence of a potential force field. It was found that the phenomenon is generally similar to that in a stationary convergent-divergent nozzle. Analysis of data from a 14-inch-diameter impeller of this type showed that the flow behavior was generally similar to that in a rotating radial channel whose inlet area varied with the operating point (Technical Note 2691).

The flow in a rotating impeller channel has been experimentally studied in a 48-inch radial inlet impeller that was instrumented to give the internal distribution of temperature and pressure. The impeller was completely investigated both as originally designed and with modified blade shapes. A region of high loss was found to generally exist along the trailing face from a combination of low-energy air shifting toward the trailing face and losses produced by decelerations along the trailing face. The investigation of the modified impeller showed that the internal efficiency can be improved by designing for proper velocity distributions (Technical Notes 2584 and 2706).

Turbine Research

The turbine component of a turbojet engine must be small, light, and efficient and as an engine component

it must match the performance of the compressor. The severe aerodynamic demands must be balanced against the limitations of material stress at elevated temperatures. Turbine research is being directed toward improved general performance and the development of means by which the optimum design can be selected for any specific application.

Since it is essential that turbine components conform to the engine specification of small size and weight, an exploratory velocity diagram analysis was made to establish the aerodynamic specifications of a single-stage turbine which would most effectively provide these characteristics. The results indicated that supersonic velocities in both the rotor and stator would be present and that the requirements would be met by an impulse diagram at the mean radius (Technical Note 2732).

A compressible-flow plotting device which can be used to obtain solutions of two-dimensional compressible flows through well-defined passages has been developed in the Langley Cascade Aerodynamics Section. This method, presented in Technical Note 2681, makes use of plastic cams which automatically set the length-width ratio of rectangles formed by stream lines and equipotential lines, which are represented by spring-steel wires. Pressure distributions around four cascades of turbine blades and along the surface of a choked nozzle determined by this method are shown to compare well with experimental results. The use of this device eliminates the need for difficult and time-consuming mathematical calculations of two-dimensional turbine-blade pressure distributions.

Turbine Cooling

Turbine-cooling research continues to be directed toward two major objectives; reduction of the critical materials content of the turbine engine necessary to withstand elevated temperatures by adequately cooling highly stressed members such as the turbine disks and blades, and development of means whereby gas turbines may be operated at higher gas temperatures to achieve large gains in engine performance.

Experimental investigations designed to achieve the first objective have been extended to full-scale applications of air cooling to a centrifugal-type turbojet engine, redesigned with turbine disks and blades of non-strategic materials. These applications have been checked under endurance and cyclic operating conditions.

The second objective has been advanced by an investigation of the alterations an existing turbojet would require to permit operation at 2,000° F. gas temperature and by continuing the investigations of transpiration and liquid cooling.

A great deal of effort has been directed toward obtaining fundamental heat-transfer data upon which present designs are based. A summary of the turbine-

cooling heat-transfer investigations is given in a paper which was presented at a general discussion of heat transfer in London in September 1951.*

The influence of light refraction on the applicability of the Zehnder-Mach optical interferometer to two-dimensional, cooled boundary layer was studied. A method is presented for estimating the refraction effects on a cooled boundary layer similar to that encountered in flow over cooled turbine blades (Technical Note 2462).

Extensive research has been conducted to develop methods for calculating local gas-to-blade heat-transfer rates in the laminar flow regions around the blade leading edge and along the surfaces so that local blade temperatures may be calculated. Transpiration cooling required modifications of the methods to account for the effects of flow through the permeable walls on the heat transfer. Analyses were made which simultaneously accounted for the effects of flow through the porous wall, large pressure gradients around the blade, and large temperature differences between the gas stream and blade. As a result the values of local heat-transfer rates sufficiently accurate for engineering applications can now be determined for permeable cylinders of arbitrary cross section with the aid of dimensionless charts which greatly decrease computation time (Technical Notes 2479 and 2733).

An understanding of the characteristics of free-convection flows with heat transfer is important to aeronautics in the design, for example, of gas-turbine rotor blades cooled by the centrifugal-force-induced free convection flow of coolant in the blade passages. As a simplification of the many free-convection flow problems, a general analysis of the free-convection flow about a flat plate parallel to the direction of the generating body force has been made. Velocity and temperature distributions have been computed therefrom for large Grashof numbers and for Prandtl numbers corresponding to those of liquid metals, gases, liquids, and very viscous fluids. It is shown that velocities and Nusselt numbers of the same order of magnitude as those associated with forced convection flows can be obtained under free-convection conditions. A flow and a heat-transfer parameter have been derived from which the important physical quantities can be computed. The analysis has been published as Technical Note 2635.

An experimental investigation of forced-convection heat transfer and associated pressure drops was conducted with air flowing through electrically heated Inconel tubes having various degrees of square-thread type roughness. Data were obtained for roughness ratios (thread height/tube radius) of 0 (smooth tube), 0.016, 0.025, and 0.037 for average stream Reynolds numbers up to 350,000, average surface temperatures

up to 1,950° R., and heat flux densities up to 115,000 B. t. u. per hour per square foot. The results showed that both heat-transfer and friction coefficients increase with increase in surface roughness. For a given roughness, both heat transfer and friction were also affected by the ratio of tube-wall temperature to air temperature. As previously found for smooth tubes, the effect of surface-to-air temperature ratio could be eliminated from the heat-transfer data by a modification of the conventional Nusselt correlation parameters wherein the mass velocity in the Reynolds number was replaced by the product of air density evaluated at the film temperature and the average stream velocity; in addition, the physical properties of air were evaluated at the film temperature. It was further found that the heat-transfer data for all the rough tubes, as well as the smooth tube, fell on a single line when the average stream velocity in the Reynolds number was replaced by the so-called friction velocity.

Work with air flowing in smooth tubes was extended to include measurement of average heat-transfer and friction coefficients with short tubes (length-diameter ratio, 15). It was found that the experimental data could be correlated by the same methods used for the longer tubes (length-diameter ratio range, 30 to 120) previously investigated.

ENGINE PERFORMANCE AND OPERATION

Performance and Operating Characteristics

The effect of compressor-outlet air bleed for cooling purposes on turbojet-engine performance was calculated by the use of an analysis based on experimentally determined component characteristics of a centrifugal-flow turbojet engine with a constant-area jet nozzle. A range of engine speeds from 90 to 100 percent rated engine speed and air-bleed rates up to 10 percent of compressor air flow were considered at a flight Mach number of 0.52 and an altitude of 24,000 feet. This investigation was reported in Technical Note 2713.

Engine Controls

Three methods of analysis in order to make possible a choice of a suitable method of determining engine dynamic characteristics are presented in Technical Note 2634. The limitations of each method of analysis are discussed with respect to the accuracy of results, ease of obtaining and processing data, and economical use of engine and test facilities.

Propulsion-System Analysis

An analytical study was undertaken to develop a simplified design method for determining the optimum turbine and exhaust nozzle design for use with a selected compressor design in a turbo-propeller engine. After the components are matched, the over-all performance of the engine for a range of operating conditions may

be predicted from the component characteristics by means of the equilibrium equations used for matching the engine. The development of the method is followed by an example in which performance maps of a turbine-propeller engine are calculated for three values of ram-pressure ratio and for a range of ratios of exhaust-nozzle to turbine-inlet area. This investigation is reported in Technical Note 2450.

The theoretical analysis of thrust augmentation of turbine-propeller engines has been completed and the results presented in Technical Notes 2672 and 2673. The effect of compressor-inlet water injection on the performance of an axial-flow compressor operating as a component of a gas-turbine engine is presented in Technical Note 2673. The augmented performance of the turbine-propeller engine is presented in Technical Note 2672. Augmentation methods considered are compressor-inlet water injection, tail-pipe burning, and their combination. Flight conditions covered vary from take-off to transonic flight at high altitudes.

The thermal lag inherent in thermocouples and resistance thermometers introduces a significant error when rapidly fluctuating temperatures are being measured. Basic electrical networks have been worked out which compensate for this as encountered in combustion research and the control of jet power plants (Technical Note 2703).

Engine Accessories

The analysis of the use of an afterburner heat exchanger (Technical Note 2456) on a turbojet engine completes the analytical evaluation of different methods of power extraction from a turbojet engine. In the analytical investigation of the performance of afterburner heat exchangers, three main phases are considered: (1) the method of analysis and the development of generalized working charts expressing the performance of unfinned heat exchangers; (2) calculation of engine performance with heat exchanger in operation; and (3) comparison of the performance of unfinned and longitudinally finned heat exchangers.

ENGINE MATERIALS RESEARCH

High Temperature Materials

Increased interest in the ceramic-metal materials called ceramals for use as turbine blade materials at high temperatures has resulted in the evaluation of the elevated temperature properties of a large number of combinations. However, there has in the past been insufficient effort directed toward understanding the reasons why a mixture of a metal and a ceramic combine most of the good points of the two components with only a few of the undesirable characteristics. The logical procedure for arriving at such an understanding consists of studying the process by which ceramals are made, beginning with the raw materials and ending with a study of the effect of fabrication veriables on strength.

Such studies were undertaken, using the simple material chromium-carbide to determine the interrelationship between grain size, grain growth, and density (Technical Note 2491). It appears that in the early stages of sintering, the grain diameter D and the sintering time t are interdependent, according to the expression $D^n = Kt$ where K is a rate constant and n is associated with the location, size, and shape of the voids in the body. However, in the last stage of sintering, the grain growth continues independently of the density.

Continuing this line of investigation, it is of interest to correlate the structural changes observed during the sintering process with the strength and hardness of the end product (Technical Note 2731). As one would expect, the room temperature strength and hardness of a simple material such as chromium-carbide are influenced by grain size and the number, size, location, and shape of the voids within the sample. However, the extent to which the sintering has progressed and the sintering conditions which will yield the optimum room temperature strength can be determined from hardness measurements. Additional information has been obtained which indicates that a large grain size is detrimental to room temperature strength, although this effect may disappear at elevated temperatures.

Evaluations of a number of ceramals indicated that titanium-carbide is a very promising base material. In the original studies, the titanium-carbide had been mixed with cobalt. In view of the relative scarcity of cobalt, an investigation was undertaken to determine whether less strategic materials, such as nickel or iron, would be suitable as binder materials. Of the two materials studied, nickel-bonded cermets had better oxidation and thermal shock resistance. Over the temperature range of 1,600° to 2,400° F., the optimum iron-bonded ceramal and the optimum nickel-bonded ceramal were not as strong as the cobalt-bonded material referred to previously, the maximum difference being on the order of 50 percent.

As a result of the need for improved alloys for high temperature use, a great number of commercial alloys have been developed in recent years. Most of these alloys contain at least five or six alloying elements. With alloys of this complexity, it is extremely difficult to establish the optimum composition range merely on an experimental basis without using a correlation between structure and strength properties as a guiding principle. In order to make use of this correlation, some knowledge of the phase diagrams concerned is necessary. A program was established at the University of Notre Dame under NACA sponsorship with the

objective of establishing at first the phase relationships of systems having two or three alloying components and then continuing by adding one new element at a time. Accordingly, a survey was made of the chromium-cobalt-nickel phase diagram at 2,200° F. by means of X-ray diffraction and microscopic studies on 110 vacuum-melted alloys (Technical Note 2602). The project was continued with the objective of determining an isothermal survey of the phase diagram for the chromium-cobalt-nickel-iron system at 2,200° F. The iron content was varied up 30 percent to include the range of the commercial chromium-cobalt-nickel alloys. In addition, some effort was placed on the cobalt-chromium-iron system (Technical Note 2603). Finally, a survey was made of the chromium-cobalt-nickel-molybdenum system at 2,200° F. The component cobalt-nickel-molybdenum, chromium-cobalt-molybdenum, and chromium-nickel-molybdenum systems were also studied. The survey of these systems was confined to the determination of the boundaries of the alpha solid solutions and of the phases existing with alpha at 2,200° F. (Technical Note 2683).

Current gas turbine blade alloys should not by any means be considered fully developed. This is particularly true of the cast alloys wherein the time-to-failure of the first specimen in the sample and the last specimen in a sample may vary by a factor of as much as 300 percent. Significant improvement may be obtained by increasing the uniformity of the material and thus reducing the spread between first and last failures. One way of doing this is through proper heat treatment which, in turn, affects the microstructure within the alloy and thus affects the alloy strength. A study of the effect of six heat treatments on Haynes Stellite alloy No. 21 in the form of small turbine blades was undertaken (Technical Note 2513). A marked improvement in the blade life could be associated with lamellar microstructure produced by a heat treatment at 2,250° F. for one hour, followed by a slow cooling to 1,800° F. The conditions of test were 1,500° F. at 20,000 p. s. i. at the midspan of the blade.

Under the sponsorship of the NACA, the University of Michigan has been conducting an investigation of the fundamental factors influencing the strength of high temperature alloys. A previous investigation had led to the redefinition of "cold working" as working at any temperature for which no appreciable internal stress relaxation occurs during the working operation or during the cooling period after such working. One unanswered question which immediately presented itself was how the response to cold working might vary with chemical composition. This was studied by determining the effect of small additions of tungsten, molybdenum, and columbium on creep properties after cold working and on internal stress relaxation characteristics of the austenitic alloy N-155 (Technical Note 2586).

It was concluded that the effects of cold working on creep resistance were the same for all the alloys studied for temperatures up to 1,600° F.

One of the problems involved in the use of the current blade alloys is the occurrence of abnormally large or "elephant" grains which, when segregated in such sections of the blade as the leading or trailing edge, may cause premature failure. As a part of the University of Michigan program, a study was undertaken to induce abnormal grain growth under controlled conditions in the laboratory in order to study the fundamental causes (Technical Note 2678). It appears that grain growth can be induced by temperature cycling alone. Studies of the critical deformation for abnormal grain growth on subsequent solution treatment indicated that the critical deformation by rolling lies between zero and two per cent. This was independent of the temperature at which the deformation was carried out. Repeated critical deformations between reheats to 2,150° F. resulted in much larger grains after solution treating at 2,300° F. than a single deformation.

For the past several years the National Bureau of Standards, under NACA sponsorship, has been conducting an investigation of the mechanisms of adherence of ceramic coatings to metals. Several previous investigations have established that hydrogen is a major cause of coating defects when a porcelain enamel is applied to a steel base. In an effort to determine the relative importance of the various sources of hydrogen, a study was made utilizing additions of deuterium in the form of heavy water in each of five different processes that are related to enameling operations. The gases which were given off when the resulting coating specimen was fired were collected and analyzed with a mass spectrometer (Technical Note 2617). The major source of hydrogen was the dissolved water present in the enamel frit that was incorporated into the coating. This water apparently reacts with steel at elevated temperatures, releasing atomic hydrogen, some of which is dissolved by the steel. During fast cooling, the steel becomes super-saturated with respect to hydrogen and, in time, molecular hydrogen forms in small fissures until sufficient pressure has accumulated to cause the coating to fail. Other sources of water, such as the acid pickle, milling water, chemically combined water in the clay, and the frit quenching water were all minor sources of hydrogen.

Continuing the investigation of adherence, the Bureau of Standards has conducted an investigation to determine the role of cobalt oxide in promoting adherence of porcelain enamels to iron (Technical Note 2695). A radioactive isotype of cobalt (CO⁶⁰) was used as the means for tracing the migration of cobalt during the firing of the enamel on the iron. It appears that when a cobalt-bearing porcelain enamel is applied to an enameling iron and fired, a cobalt-bearing phase is

formed at the enamel-metal interface. The amount of the deposit formed will vary directly with the severity of the firing treatment and appears to be metallic rather than a silicate or oxide.

ROCKET RESEARCH

Research investigations on rocket engines during the past year have included studies of combustion, ignition, and cooling.

Pulsating propellant flow is a problem in rocket motor operation requiring special research instrumentation for proper study. An electromagnetic flowmeter, as a means of measuring instantaneous flow rates of liquid propellants, has been designed and tested on a rocket engine. This instrument may be used with a number of fluids of widely variable properties and will measure rapid variations in flow rates not detected by previous instrumentation. The electromagnetic flowmeter is capable of remote operation and will respond to positively or negatively directed flow.

In an effort to reduce the total instrumentation required for rocket research, a well-protected central control room with connections to outlying test cells has been developed. Means of recording accurately a number of temperatures and temperature differences as measured by thermocouples located in the various test cells had to be provided. This required that, within a few minutes, the central instruments be disconnected from one test installation and connected to another and that the ranges of the instruments be altered to suit the needs of the new installation. This has been made possible, in part, by the development of a special, multistage, self-balancing potentiometer that may be quickly adjusted to measure and record the expected temperature ranges and temperature differences. The outstanding characteristics of the instrument are the techniques of reference-junction compensation and of simultaneous span alteration that permit the rapid selection of any one of a large number of ranges.

The heat transfer and frictional pressure drop of nitric acid flowing in tubes is important in the possible use with regeneratively-cooled rocket engines. As a result of the special corrosive and decomposition properties of nitric acids, a special design study of apparatus suitable for determining these heat transfer and frictional pressure drop properties of nitric acid flow through heated tubes was contracted for and made by Purdue University.

Adequate cooling of a liquid-propellant rocket engine is one of the important challenging problems to be solved if higher-energy propellants or higher combustion pressures are to be used to obtain superior performance from rocket engines. Internal-film cooling, wherein a coolant film is formed between the hot gases and the duct wall to maintain the wall at low temperature, may be used in such cases.

A general investigation of internal-liquid-film cooling is being conducted by the NACA to obtain a correlation of experimental data that will allow predictions of film-coolant requirements for specific cooling problems. One phase of the fundamental investigation was conducted in small diameter straight tubes having smooth inner surfaces with hot-air flows at temperatures to 2,000° F. to determine the cooling effectiveness of water films on the inner surfaces. Correlation was obtained for heat transfer between flowing hot air and liquid films over a range of air flow and temperature for constant coolant flows. Heat-transfer correlations obtained were dependent upon coolant flow.

The generalization of all the film-cooling data obtained with smooth-surface tubes is intended to facilitate the estimation over a wide range of conditions of the flow of coolant required to film cool a tube for a desired distance when the temperature and flow of the hot gas are known.

PHYSICS OF SOLIDS

The development of a suitable shielding material will have a considerable effect upon the success or failure of a nuclear powered airplane. To find the most efficient shield for a given source of radiation, many combinations of materials must be considered. Because of the difficulties of calculation, direct measurement seems the proper procedure. However, to try all of the possibilities would require a large volume of experimentation. In order to avoid the need for elaborate computation and for large-scale experimentation, earlier work at the NACA had proposed a method for predicting the effectiveness of composite shields on the basis of actual measurements made on a relatively small number of homogeneous shields. The basic idea presented was to treat the shield as being composed of a number of layers or elements, upon each of which the required measurements of shielding effectiveness had been made. Recent work directed toward simplifying this method has resulted in the determination of approximate solutions of the transport equation for two special conditions: first, that in which multiple elastic scattering dominates, and second, that in which the role of multiple scattering with change in direction is small compared with other effects (Technical Note 2647). The results obtained serve three purposes: (1) They demonstrate the importance of taking into account the direction of motion of the particles; (2) they provide a means for calculating the effect of any element which is not too thick and in which multiple elastic scattering is not too important an effect, from the results of measurements on an infinitesimal element of the same material; and (3) they suggest a way of simplifying the computations necessary in the application of the semi-empirical method.

Previous studies at Ohio State University had indicated the desirability of utilizing the helium isotope (He³) and the tritium (H³) nuclei as bombarding particles in a cyclotron. Because of the extreme rarity of these elements and radioactive nature of H³, a new method of introducing and circulating them was required. Such a system was developed by the Ohio State University under NACA sponsorship (Technical Note 2573). Although no actual bombardments in the cyclotron were made during the course of this project, it is believed that with a sufficiently increased pumping speed the circulating system would provide satisfactory operation.

A possible method for measuring the current of an ion beam in an accelerator would be to measure the absolute thick target yield for a known reaction caused by the ions and, from this, to calculate the average current. Such a method has been developed by the Ohio State University under NACA sponsorship (Technical Note 2627). It appears that the average beam current in a cyclotron can be calculated from the number of disintegrations per second observed, the half life of the radioactive substance formed, and the reaction cross-section.

In an attempt to devise a convenient method for examining the distribution of particles in a cyclotron beam, the Ohio State University, under NACA sponsorship, developed a radioautographic method utilizing activated metal foil (Technical Note 2650). The method has been confirmed by direct comparison of density values and count rates and has also been verified for higher energy components of the β-rays emitted from the foils.

An experimental investigation was made of the forced-convection heat-transfer characteristics of a eutectic mixture of lead and bismuth. Data were obtained for lead-bismuth eutectic flowing in a circular tube with heat addition, and for lead-bismuth eutectic flowing in an annulus with heat extraction from the inner surface. Data were obtained both with the pure eutectic and with about 0.04 percent by weight of magnesium added to the lead-bismuth eutectic to promote wetting of the heat-transfer surfaces. The investigation covered an over-all range of Peclet numbers (Reynolds number multiplied by Prandtl number) from 250 to 3000. Measured values of Nusselt number were considerably lower than values predicted by equations generally used for liquid-metal heat transfer. The addition of magnesium to promote surface wetting resulted in no change in the heat-transfer characteristics of the lead-bismuth eutectic.

An experimental investigation is being made of the forced-convection heat-transfer characteristics of molten NaOH. The data obtained to date fall on the conventional correlation line for fluids with Prandtl numbers in the vicinity of 1.0.

In an attempt to explain the disagreement between experiment and previous analyses of liquid-metal heat transfer, an analysis was made of heat transfer for fluids flowing turbulently at low Peclet numbers in smooth tubes. The mixing-length theory was modified to account for the heat being continuously transferred by conduction to a turbulent particle as it moves transversely across the tube. The predicted results are brought into considerably better agreement with experimental data than previously, both for liquid metals and gases at low Peclet numbers.

An analysis was made to determine the effective thermal conductivity of a powder from the fraction of space occupied by the gas, and the thermal conductivities of the solid and the gas which make up the powder. In order to check the analysis, tests were conducted to determine the conductivity of magnesium oxide powder in various gases (air, argon, and helium) at temperatures between 200° and 800° F. The effect of gas pressure on thermal conductivity was also checked. Good agreement was obtained between analytical and experimental results.

AIRCRAFT CONSTRUCTION

The gradual build-up of NACA research in the field of aircraft construction which was started 2 years ago is continuing. The new environment in which modern airplanes must operate has brought with it unusually complex problems which will be with us for many years.

Aircraft structures must now be designed to withstand the high temperatures resulting from aerodynamic heating at supersonic speeds plus the attendant complications brought on by increased air loads. The need for thinner wings and slenderer fuselages, also dictated by high speed, introduces flutter and dynamic response problems so difficult that they cannot be solved by known theoretical means but must be studied in all their complexities by dynamic models. The importance of the proper selection of materials for aircraft structures is obvious when confronted with the design problems just mentioned and the need for materials with higher stiffness and higher strength at elevated temperature is apparent.

Much effort has been spent during the past year in studying the need and planning for new research facilities to make possible adequate progress toward the solution of these new problems. However, new facilities will not be available in the near future so in the meantime we are investigating those phases of the problems that lend themselves to our present facilities.

As in the past a portion of NACA's research in this field was performed under contract at universities and other non-profit scientific institutions. A description of the Committee's recent unclassified research on aircraft construction is given on the following pages and is divided into four sections: Aircraft structures, aircraft loads, vibration and flutter, and aircraft structural materials.

AIRCRAFT STRUCTURES

Stress Distribution

Many of the current engineering analyses do not predict accurately the stress distribution in fuselages, reinforced by rings and stringers, in which the rings are loaded in their planes. The more flexible the rings relative to the rest of the fuselage structure, the more inaccurate are the analyses. Since 1940 many publications have appeared treating this subject with more refined and complicated analyses, but all have dealt with fuselages with circular cross sections. Hence, in Technical Note 2512, a method is presented for finding the effects of flexibility on noncircular fuselages which are com-

posed of a number of circular arcs. This method is based upon a general eighth-order differential equation applicable to each of the circular-arc sections. Numerical examples showing the effects of radial, tangential, and moment loads are given.

In order to evaluate the structural efficiency of sandwich construction consisting of light-weight balsa core material and 75S–T6 aluminum-alloy faces, a comparison has been made in Technical Note 2514 of the weights of such sandwiches and of conventional skin-stiffener construction for the upper surface of wings. This comparison shows that the sandwich becomes more efficient than conventional construction only for thick wings having relatively thick skins. The report also shows that sandwiches with thick faces and thin cores are most efficient for resisting the compression encountered in the upper surface of a wing.

A method has been developed by Pennsylvania State College for the analysis of the deformation of doubly-curved thin plates. This method, which is presented in Technical Note 2782, is particularly useful for analyzing fuselage coverings in which the radius of curvature in one direction is large.

One of the present trends in the development of high-speed airplanes and missiles is toward the use of thin wings of low-aspect-ratio. The structural analysis of these wings often cannot be based on beam theory, since the structural deformations may vary considerably from those of a beam and more closely approach those of a plate. In wings that are solid or nearly solid, the use of plate theory in the analysis is particularly valid. In Technical Note 2621, the structural analysis of solid cantilever wings of arbitrary plan form by this plate theory is reduced to the solution of linear ordinary differential equations by use of the assumption that the chordwise deflections may be expressed in the form of a power series. With the series limited to the first two and the first three terms, the differential equations are solved exactly for several examples of solid delta wings. For cases for which exact solutions to the differential equations cannot be obtained, a numerical procedure is derived. Some experimental data are presented and are found to compare favorably with the present theory.

One method of solving the three-dimensional stress problem photoelastically utilizes the removal of slices from the stressed model and measuring the strains in the slices after annealing. In order for this method to be successful, model materials must possess values of Poisson's ratio considerably lower than those for ma-

terials now available. A new general method has been developed for the photoelastic determination of the principal stresses at a point of a general body subjected to arbitrary loads. This method, which was developed by the Illinois Institute of Technology, does not depend upon Poisson's ratio. The stresses existing in a sphere subjected to compression have been determined with considerable accuracy.

The practical design of sheet elements carrying shear loads was for a long time based on one of two limiting assumptions: it was assumed either that the sheet did not buckle at all, or else that the sheet buckled as soon as a very small load was applied. Standard civil-engineering formulas were based on the first assumption. The analytical theory of pure diagonal tension developed by Wagner was based on the second assumption. The use of two distinct methods of analysis was unsatisfactory because actual structures always work somewhere between the limiting cases. A number of years ago, the NACA began to develop a unified method based on a simple theory that would cover the entire range. Through extensive experimental investigations, some of which were performed by the aircraft industry, the methods for analyzing flat webs were developed and then extended to curved webs. The advantages of this theory are that all the results previously obtained for flat webs can be utilized and the method is applicable to webs of any curvature.

A number of NACA reports on the work have been published since it was started and a certain degree of completion has now been reached. A summary has therefore been prepared which contains all the essential information and supersedes all previous papers on individual phases. The summary is divided into two parts. Part I (Technical Note 2661) presents the methods of analysis, whereas Part II (Technical Note 2662) presents the experimental evidence.

Structural Stability

Shear webs in thin wings of aircraft are subjected to a combination of bending, shear, and transverse compression, the transverse compression being induced by spanwise bending of the covers. In Technical Note 2536 the buckling strength of an unstiffened infinitely long flat plate under such a loading is computed approximately by the minimum-potential-energy method, and three-dimensional interaction surfaces are presented for the computation of the combined stresses which cause elastic buckling. Surfaces are presented for two sets of edge conditions: both edges simply supported, and lower edge simply supported with upper edge clamped. Present results are in good agreement with those for one-load limiting cases previously published.

The use of sandwich construction for compression-carrying components of aircraft often required the calculation of the compressive buckling strength of curved sandwich plates. Theoretical solutions are presented in Technical Note 2601 for the buckling in uniform axial compression of two types of simply supported curved sandwich plates: the corrugated-core type and the isotropic type. The results are given in the form of equations and curves.

The so-called "double skin" construction, consisting of inner and outer flat skins riveted to the crests and troughs of a corrugated sheet sandwiched between the flat skins, has been used on a number of aircraft in those locations at which it is inconvenient to provide auxiliary supporting members—such as ribs or bulkheads—for the skin. The stability of this double-skin or corrugated-core sandwich construction under longitudinal compression is investigated theoretically in Technical Note 2679 and charts are presented for the calculation of the buckling of such sandwiches of various proportions.

The use of simple posts rather than continuous ribs, or shear webs to keep the compression skin of the wing from buckling has many advantages from the standpoint of accessibility and ease of production. A theory for the calculation of the buckling loads for such post-stiffened construction has been derived and charts are presented for a wide range of combinations of post sizes and spacings (Technical Note 2760).

AIRCRAFT LOADS

Steady Flight Loads

A series of charts and approximate formulas for estimating aeroelastic effects on the spanwise lift distribution, lift-curve slope, aerodynamic center, and damping in roll of swept and unswept wings operating at subsonic and supersonic speeds are presented in Technical Note 2608. In the derivation of the charts, two types of stiffness distribution are considered, one which consists of a variation of stiffness with the fourth power of the chord and one which is based on an idealized constant-stress structure. This set of charts serves to simplify design procedure at the preliminary stage and indicates the amount and location of material required to stiffen a wing which is adequately strong so far as normal loads are concerned but which is not stiff enough torsionally. The charts also facilitate the achievement of wings in which opposing twist effects are so balanced against one another as to reduce aeroelastic effects to a minimum.

Maneuvering Loads

Recent experiences have indicated that sideslip angles in rolling maneuvers may be critical to the vertical-tail design of airplanes having weight distributed mainly along the fuselage. Available methods for estimating the maximum angles of sideslip in rolling maneuvers

are compared in Technical Note 2633. The results of this study indicate that existing simplified expressions for calculating maximum sideslip angles to determine vertical-tail loads in rolling maneuvers are not generally applicable to airplanes of current design. The results further indicate that a general solution of the three linearized lateral equations of motion, including product-of-inertia terms, usually will be sufficient to determine the sideslip angles expected in aileron rolls from trimmed flight. In rolling pull-outs, however, when the pitching velocity is rapid, consideration of cross-couple inertia terms in the equations of motion is necessary to obtain the sideslip angles accurately. The inclusion of the equation of pitching motion along with the lateral equations of motion seems desirable in order to obtain the influence of pitching in the cross-couple inertia terms of the lateral equations. The results also indicated that pitching oscillations started during rolling maneuvers will be influenced by cross-couple inertia moments in pitch and may cause large variations in angle of attack which affect horizontal-tail loads.

Gust Loads

The NACA VGH recorder, which gives a time-history type of record, is being used more and more to supplement V–G data particularly for obtaining information on the small but frequent loads which are obscured in the V–G record. Because of the widespread interest in the VGH data an analysis of limited samples of data from four types of transport airplanes was undertaken. This analysis showed a decrease in the number of loads of a given intensity with altitude up to 25,000 to 30,000 feet, the limit of the sample. Meanwhile additional VGH data were accumulated on a two-engine low-altitude transport-type airplane in operation on a northern transcontinental route. Eight hundred thirty-four hours of data from this operation have been analyzed to determine the relation of the frequency and magnitude of gusts experienced to airspeed, altitude, season of the year, and flight condition. A synthesis of the VGH data and V–G data was also derived to give a composite estimate of the over-all gust history for these operations. The results of this study are presented in Technical Note 2663.

A major problem in connection with the analysis of gust-loads data is the development of suitable methods for handling such data statistically. In Technical Note 2260, the statistical concepts of random variables and probability distributions are applied to the sharp-edge-gust formula. Expressions are derived for the frequency distribution of gust loads in terms of distributions of the related variables such as airspeed and effective gust velocity. Results calculated by the derived method are compared with available flight-loads data with good agreement.

In the study of transient flows, two types of airfoil motions have special significance—a harmonically oscillating airfoil and an airfoil experiencing a sudden change of angle of attack. The lift function for an airfoil undergoing a sudden change in angle of attack and the lift function associated with the growth of lift on an airfoil due to penetration of a sharp-edged gust are commonly referred to as the indicial lift functions. By use of the reciprocal equation for compressible flow, the indicial lift and moment function of a two-dimensional sinking airfoil have been determined from oscillatory lift coefficients for Mach number 0.7 and a comparison has been made with results for Mach number 0.0, the incompressible case (Technical Note 2652). Similar calculations have been made for the pitching airfoil at Mach number 0.7 in Technical Note 2613.

Gust-tunnel investigations of the loads on swept wings have indicated that the slope of the lift curve applicable to gust conditions is a function of the cosine of the angle of sweep. Since the delta wing might be considered a special form of swept wing, an investigation was carried out in the Langley gust tunnel with a delta-wing model having the leading edge swept back 60°. The results indicated that the gust load was greater than would be predicted by using a lift-curve slope based on steady-flow force tests. The use of a value of lift-curve slope based on aspect-ratio considerations gave calculated loads which were in good agreement with the measured ones.

Theoretical investigations have indicated a decrease in gust loads with increasing static longitudinal stability. In order to obtain some experimental data on this subject, a cooperative flight investigation was undertaken by the NACA and the All Weather Flying Division of the U. S. Air Force. Two jet-propelled airplanes, similar except for center-of-gravity location, were flown side by side through rough air and the resulting loads compared. The results of the tests indicate that a forward movement of the center of gravity tended to reduce the gust loads (Technical Note 2575).

A summary of the gust-load and airspeed data from commercial transport airplanes collected during the period from 1933 to 1945 has been issued as Technical Note 2625. The data were obtained from V–G records covering more than 90,000 flight hours on six types of transport airplanes on domestic and overseas routes.

Landing Loads

An investigation of the air-compression process during drop tests of a small oleo-pneumatic landing gear is reported in Technical Note 2477. The dropping weight of the gear ranged up to 2,500 pounds and the vertical velocities at contact up to 11 feet per second. The results from these tests indicate that the value of the air-compression exponent had little effect during the

greater part of the impact, but, near the end of the impact, air-compression processes might have some effect on the total load. The value of the polytropic exponent ranged from 1.01 to 1.10 and the air-compression processes in these tests can be adequately represented by a polytropic exponent of 1.06.

In order to investigate the effects of variations in wing lift and airplane weight on the landing-gear loads, drop tests have been made with a small landing gear. Wing lift was simulated by the mechanical application of lift force which was constant throughout a given impact. The tests covered a range of wing-lift factor of 0 to 2.0, vertical velocities at contact of 0 to 12 feet per second, and dropping weights from 1,000 to 2,500 pounds. In general, an increase in the wing-lift factor reduced the landing-gear loads by an amount which was roughly equal to the incremental lift force. An increase in airplane weight resulted in the increase in landing-gear loads which was not proportionally as large as the weight increase (Technical Note 2645).

An analytical study was made of the rigid-body dynamics of airplanes during eccentric landings, and an impulse momentum method developed for calculating landing contact conditions for successive impacts in such landings. These contact conditions, which include landing-gear velocity, effective mass, and airplane attitude at contact, govern the energy-absorption requirements of the gear. The analysis includes evaluation of vertical, horizontal, and side drift velocities, wing lift, roll and pitch angles and velocities, landing-gear location, energy-absorption efficiency, and wheel angular inertia. Application of the analysis indicates that landing impacts in eccentric landings can be more severe than those in symmetrical landings with the same sinking speeds. The results of this investigation have been published in Technical Note 2596.

One investigation has been made of water-pressure distributions during landings and planing of a heavily loaded rectangular flat-plate model. Initial impact conditions and maximum pressures are presented in tables and figures (Technical Note 2453) for all impacts together with the time histories of the pressure distribution, draft, vertical velocity, vertical acceleration, and wetted length.

A semiempirical procedure for computing the water pressure distribution on flat and V-bottom surfaces during impact or planing is presented in Technical Note 2583. For the rectangular flat plate, a consideration of several previous theoretical derivations and some observations of the experimental data lead to the development of simple equations which are in good agreement with experimental data for trims below 30° and for wetted-length-beam ratios at least up to 3.3. For a V-bottom prismatic surface with appreciable chine immersion, the pressures on chine-immersed sections of a model having an angle of dead rise of 30° were found to be very similar to those on the corresponding flat plate so that a simple modification of the flat-plate equations can be used to predict approximately the pressures on V-bottom surfaces.

VIBRATION AND FLUTTER

Oscillating Air Forces

Increasing use is being made of highly swept and triangular wings for supersonic flight. A knowledge of the air forces and moments on such wings undergoing oscillations is of paramount importance to the flutter analyst. Technical Note 2457 contains a study of the triangular wing with subsonic leading edge undergoing sinusoidal torsional oscillation and vertical translation. The air forces and moments are obtained by deriving the linearized velocity potential in the form of a power series involving a frequency parameter. Technical Note 2467 contains two approximate methods for deriving the oscillatory air forces and moments on a swept wing with supersonic leading and trailing edges. A similar study for triangular and related wings with supersonic leading and trailing edges is reported in Technical Note 2494.

When linearized supersonic theory is applied to the case of a non-oscillating wing at sonic speed, infinite values of lift and moment are predicted. However, it has been found that for the case of the oscillating wing or aileron, finite values are obtained. Thus, in Technical Note 2590 explicit expressions for the lift and moment are developed for vertical translation and pitching of the wing and rotation of the aileron. Tables of coefficients for use in wing-flutter calculations are included as well as some bending-torsion flutter calculations.

Wind-Tunnel Wall Corrections

An analytical investigation has been made of the effect of wind-tunnel walls on the oscillating air forces for two-dimensional subsonic compressible flow. The tunnel walls were simulated by the usual method of placing images at appropriate distances above and below the wing. It was shown that for certain conditions of wing frequency, tunnel height, and Mach number, the tunnel and wing may form a resonant system so that the forces on the wing are greatly changed from those having no tunnel-wall effects (Technical Note 2552).

Flutter of Low-Density Wings

An experimental study using light uniform cantilever wings has been made to determine the effect on the flutter characteristics of such parameters as fluid density, positions of the wing elastic axis and center of gravity, the ratio of bending frequency to torsional frequency, and aspect ratio. The experiments were

conducted for a range of density corresponding to a variation in altitude from sea level to 40,000 feet. For each case of experimental flutter, a theoretical calculation for the corresponding conditions at flutter was made. In general, the theoretical results followed the trends shown by experiment except at very low values of the relative-density parameter.

Swept Wing in Pure Bending

It is theoretically possible for a sweptback wing which has infinite torsional stiffness to flutter in pure bending. Although no actual airplane wing can have infinite torsional stiffness, a study of the bending-alone case is of value inasmuch as it is more easily and quickly made than one for coupled flutter and the parameters affecting the bending-alone flutter may be expected to have similar effects on the coupled flutter speed. An analysis, presented in Technical Note 2461, uses aerodynamic coefficients of two-dimensional incompressible flow and includes effects of wing-mass-density ratio, sweepback, length-semichord ratio, and Mach number. Compressibility was shown to have a greater effect on the speed of pure-bending flutter and closely related coupled flutter for swept wings than on coupled flutter of unswept wings.

Control-Surface Flutter

Various investigations have been made in the past of the possibility of single-degree-of-freedom flutter involving pitching of the wing or the bending of a swept wing. In Technical Note 2551 a parallel investigation was made of the effect of various parameters, including Mach number, on the single-degree-of-freedom flutter of a control surface. This paper demonstrates that flutter of a single-degree-of-freedom control surface is possible. The effects of structural damping, aerodynamic balance, axis of rotation, and compressibility are included. The mechanisms of instability are based on potential flow and therefore the results are not directly applicable to separated flow.

Structural Damping of an Airplane Wing

The structural damping of an airplane wing may have an important effect upon the flutter characteristics. An investigation of the structural damping of a full-scale airplane wing undergoing vibration showed the damping to increase markedly with the amplitude of vibration (Technical Note 2594).

Lateral Vibrations of Hollow Thin-Walled Beams

Because of secondary effects such as shear lag, transverse shear deformation, and longitudinal inertia, the elementary theory of bending vibration is not adequate for the accurate calculation of natural modes and frequencies of hollow thin-walled cylindrical beams. In Technical Note 2682 general solutions for the modes and frequencies of such beams are given and the combined

and separate influences of the secondary effects are shown quantitatively. The general solutions presented for cylinders of uniform thickness and the numerical results presented for rectangular box beams will be useful in assessing the accuracy of simplified procedures developed for the calculation of modes and frequencies of thin-walled box beams.

AIRCRAFT STRUCTURAL MATERIALS

Fatigue

The problem of fatigue failure of materials under various types of loading is important to the designers of structures and structural elements. Efficient design of equipment is dependent upon the knowledge of the material used. Fatigue failure plays an extremely important role in the type of material used, shape of the element designed, and methods of fabrication. The University of Illinois has recently completed a study dealing with fatigue failure of 76S–T61 aluminum alloy under several conditions of combined stress. The observed modes of fracture under these conditions are described, and a qualitative theory on the mechanism of formation and propagation of fatigue cracks is proposed. An attempt to interpret the observed failures by means of this theory is also made.

The evaluation of stress concentration factors due to geometric discontinuities is necessary to predict the static strength of parts made of materials with low ductility and the fatigue strength of any part containing such discontinuities. Because of analytical difficulties, theoretical studies of stress concentrations have been limited to simple geometric shapes and, until recently, to the elastic stress range. An experimental investigation was undertaken to determine the elastic stress concentration factors for several shapes not previously treated and to determine the reduction of these factors as the material was stressed in the plastic range. The specimens used were large enough to permit determination of highly localized maximum stresses. The elastic stress concentration factors were found to agree with companion photoelastic tests within the combined experimental error of the two investigations. Reasonable agreement was also found between results of these tests and predictions by theoretical considerations of similar, but not identical shapes. The plastic stress concentration factors were found to agree well with a generalized form of an expression for plastic stress and strain concentrations at a circular hole in an infinite plate, reported previously in Technical Note 2073. The results of this more recent investigation are presented in Technical Note 2566.

Creep

The behavior of materials under load at elevated temperatures must be fully understood to enable the

most efficient design of many structural elements. Creep, the plastic deformation of materials under load, is one of the basic phenomena associated with high temperature. Accordingly, a study into the basic nature of creep of materials under load has been undertaken at the Battelle Memorial Institute. Many theories have been proposed to predict the creep behavior of materials, but many gaps exist even in these theories, and the experimental work in the literature does not cover a sufficiently wide range of possible conditions to be of great aid in the design of structures or structural elements. The portion of this program reported in Technical Note 2618 covers that phase of the research dealing with creep in high purity aluminum under constant load and constant temperature. Agreement is obtained with the exhaustion creep theory of Mott and Nabeno at low stresses, while at the higher stresses agreement is obtained with the ideas expressed by Andrade.

Plasticity

In Technical Note 2576 a qualitative check on the basic assumptions of several different theories of plasticity is given by photomicrographs of the surface of a 2S–O aluminum-alloy specimen subjected to tensile strains ranging between 0 and 3 percent. The manner in which the inception and development of slip lines took place is compatible with, but does not necessarily verify, the conception that plastic deformation is primarily due to slip. Slip was observed to occur first in a few isolated grains and to spread gradually to adjacent grains as the stress level increased. The occurrence and spread of the slip lines suggested independent behavior of randomly oriented grains at low stress levels, with interaction among grains increasing as the stress level increases. In Technical Note 2577 an attempt is made to assess quantitatively the assumptions on which

one of the more recent theories of plasticity, the so-called "slip theory," is based. This assessment is made by comparing an experimental distribution of the frequency of the angular orientation of the slip lines with theoretical distributions calculated for the same model as that used in formulating the stress-strain laws of the slip theory. Although good agreement is obtained in the shape of the distributions, the comparison between the experimental maximum slip angle and that predicted by the theory is not very good.

Plastics

Loss of strength in plastic glazing due to crazing of the material has become a vital factor in the design of aircraft cabin enclosures. Pressurization of commercial and military aircraft has become commonplace, and plastic glazing failure due to crazing has brought about the need for continued research into the effects of temperature and load on the strength characteristics of plastics before and after crazing. The National Bureau of Standards is continuing its work on polymethyl methacrylate and reports in Technical Note 2778 a study of the stress and strain values at various temperatures at the onset of crazing. In the temperature ranges studied (23° to 70° C.), it was found that the average stress at craze onset was 80 to 95 percent of the tensile strength. In Technical Note 2779, the effects of biaxial stretch forming on the tensile and crazing properties of polymethyl methacrylate are reported.

Moderate biaxial stretch forming up to 50 percent greatly increased the stress threshold of crazing and the strain and total elongation at craze onset but did not effect the tensile strength and secant modulus. The stress threshold of stress crazing was increased approximately 40 percent for times up to 7 days, and the stress threshold for stress-solvent crazing increased about 70 to 80 percent.

OPERATING PROBLEMS

Inadvertent Speed Increases in Transport Operation

Some factors relating to inadvertent speed increases in transport operation have been investigated with the object of indicating the manner in which speed gains might vary with different qualities of the airplane and the minimum margins required to guard against reaching unsafe values. The speed increments and the margins required under several assumed conditions were studied analytically, and the results indicate that, on a percentage basis, smaller margins would be necessary for high-speed airplanes than for low-speed airplanes to prevent overspeeding in inadvertent maneuvers (Technical Note 2638). In addition, the possibility of exceeding placard speed in prolonged descents is shown by computations for typical transport airplanes, and equations are suggested that allow estimates to be made of the speed margins required.

Ditching

Information obtained from a large number of NACA model ditching investigations has been compiled and summarized to provide airplane designers with a considerable amount of data for current airplane designs. This summary of the effects of design parameters on ditching characteristics enables the designer to choose configurations that will tend to give better ditching performance than would ordinarily be obtained if no consideration were given to ditching requirements.

To further determine the effect of fuselage shape on ditching behavior, various airplane models having different fuselage shapes have been tested. Design parameters such as fuselage fineness ratio, bottom curvature, and bottom strength were included in the analysis to investigate their effect on airplane ditching characteristics.

AERONAUTICAL METEOROLOGY

Summary of Hail Information

A survey of the present knowledge of hail phenomena in relation to aircraft operation has been completed and is presented in Technical Note 2734. Information is given on the physical properties, occurrence, and theories of formation of hail; and data relating to the types and extent of damage to aircraft are correlated with the size, intensity, and geographical location of hailstorms. Airborne radar detection of hailstorms and the elimination of potential storms by cloud seeding are discussed briefly. In addition, an extensive and annotated bibliography on hail is furnished for use of research personnel.

High Altitude Turbulence Data Collection

In order to obtain more information concerning high altitude turbulence, two programs are currently under way to collect and analyze data on this meteorological phenomenon. With the assistance of the Weather Bureau and the cooperation of military services and airlines, pilots are reporting encounters of clear air turbulence above 10,000 feet, for the airlines, and above 25,000 feet, for military aircraft. The completed reports are being analyzed to obtain preliminary statistics on the frequency and severity of high altitude clear air turbulence; and an attempt will be made to apply the facts established in developing methods of predicting such turbulence.

The second program for the collection of high altitude turbulence data utilizes the NACA turbulence telemeter. Daily instrument ascents are made at 1400 Z from four Weather Bureau stations at Caribou, Maine; Greensboro, N. C.; Miami, Fla.; and Grand Junction, Colo. An 800-gram balloon bursts at approximately 60,000 feet and releases the telemeter-parachute assembly which transmits a time history of the vertical accelerations experienced during the descent. The telemeter data is then integrated to give comparative gust velocities encountered by the parachute.

Atmospheric Turbulence and Climb Performance

To determine some of the effects of turbulence on climb performance, a series of flight tests in smooth air and under conditions of light turbulence were performed with a twin engine transport airplane, restricted to the one-engine-inoperative condition. The results of the flight tests (Technical Note 2498) indicated that light turbulence of the type generally present in clear air over flat terrain had no significant effect on the average rate of climb for a series of runs. Turbulence did, however, increase the variation in the rate of climb from run to run. The standard deviation of the rate of climb between runs attributable to turbulence decreased rapidly when the duration of climb was increased from 1 to 5 minutes. The effects of atmospheric turbulence on the variations in the rate of climb appeared to be largely independent of the center-of-gravity location.

Physics of the Icing Cloud

In order to produce aircraft that are capable of flight in icing conditions, the aircraft ice protection system designer must have information on the meteorological conditions which cause icing and the probability of encountering specific values of these conditions. The important meteorological factors conducive to aircraft icing have been previously published in Technical Note 1855. However, this information provides no indication of the probability of encountering or exceeding various degrees of icing severity. To supply this additional information, a statistical study has been made of all available meteorological icing data obtained in flight through natural icing clouds. A report has been published (Technical Note 2738) which provides an indication of the probability of encountering or exceeding icing conditions of a selected severity. Although considerably more data is required to establish a statistical basis for the determination of these probabilities, a procedure has been established for a statistical analysis of meteorological data now being obtained on a world-wide basis. The initiation of a program by the Lewis Laboratory of the collection of these data utilizing an NACA pressure-type icing-rate meter on Airline, Air Force, and NACA aircraft has been previously reported. This program is continuing, and it is anticipated that an additional year of data collection should provide a substantial basis for the application of the aforementioned statistical analysis. Additional emphasis on meteorological data collection is being applied to obtain much needed data at higher altitudes so that a reasonable prediction of icing conditions can be made for the altitude ranges that are being and will be experienced by present-day and future aircraft.

The Lewis Laboratory is continuing to make progress toward understanding the fundamental processes involved in the formation of the supercooled cloud droplets. X-ray defraction studies have been used to investigate the internal structure of supercooled water. It has been shown that the structural properties of supercooled water are such that the water becomes progressively more ice-like as the temperature is lowered (Technical Note 2532). This current interest in the properties of supercooled water is due, in part, to increased research on aircraft icing, condensation, shock in supersonic flow as well as naturally and artificially induced precipitation from clouds. As a result of this interest, need has arisen for an extension of the data on surface tension of water as presented in the International Critical Tables. The experimental results extending these surface tension measurements to −22° C are reported in Technical Note 2510.

Another part of the study of supercooled droplets includes the determination of spontaneous freezing temperatures of water droplets, some results having been previously published in Technical Notes 2142 and 2234. An additional investigation of these phenomena has been completed for the case where droplets are suspended freely in an atmosphere of cold air. These results are compared with those obtained with droplets that were supported on a surface.

Icing Instrumentation

Probably the most difficult icing parameter to obtain in flight is that of droplet size. One method that has been evolved by the Lewis Laboratory concerns the placement of an electric charge on the droplets in flight. These charged droplets are then channeled to a series of different sized cylinders where they impinge and simultaneously deposit their charge. This instrument is described in Technical Note 2458. Another method of measuring droplet size in flight utilizing an adaptation of a cascade jet impactor has been investigated and reported.

The Ames Laboratory has developed an instrument for measuring icing severity in flight (Technical Note 2615). Since it is believed that icing severity is mainly a function of the amount of water present in the air at temperatures below freezing, an instrument which will record liquid water content in a cloud is essentially an icing severity meter. This instrument has been tested in simulated clouds and in an icing tunnel, and a flight version is being prepared for tests in natural icing conditions. The instrument consists of a small loop of heated wire, the temperature of which is proportional to the icing severity.

ICE PROTECTION SYSTEMS

In order to provide information on the distribution of heat requirements of a surface to be protected from icing, the area, extent and rates of the impingement must be known. Water droplet trajectory calculations around low-drag, high-speed airfoils are being made utilizing the NACA water droplet trajectory analogue. The calculations for a 12 percent thick airfoil which is the first of this series have been completed and are being published. These results are compared with theoretical calculations and will be further compared with other experimental techniques that are being developed.

For several years there has been a controversy concerning the validity of the results of icing studies conducted in a simulated cloud in an icing wind tunnel when compared with those results obtained under natural icing conditions in flight. The results of an investigation which utilized the same airfoil under almost identical conditions in flight and in the icing tunnel have shown that heat transfer coefficients obtained are very closely correlated for both the laminar and turbulent flow conditions. (Technical Note 2480)

Equations expressing heat transfer from wetted surfaces during ice prevention are complex and tedious operations for the designer of aircraft ice protection systems. A simplified method of regrouping these equations to permit solutions by a single graphical means has been evolved and is presented in Technical Note 2799.

Experimental studies of cyclic de-icing systems for fixed surfaces utilizing electric and hot-gas methods of heat source have been conducted. The results indicate that heat savings of the order of 75 percent may be achieved with cyclic heat systems when compared with the continuously heated systems. The results also indicate the relative value of continuously- and cyclically-heated parting strips. Thus, the designer is furnished data upon which possible solutions to the problems of higher demand for heat requirements especially for high-speed aircraft, may be solved.

The design of electrical heaters for propeller ice protection is complicated by the large number of variables involved; for example, blade thickness and material, heater material, extent of heater on blade surface, ratio of "heat-on" time to "heat-off" time, and intensity of heat supplied per unit of surface. To investigate these variables in flight or in an icing tunnel is a lengthy and expensive procedure. To alleviate this situation, resort has been made to the electrical analogue, which is a device in which heat flow is simulated by electrical flow. With this analogue, tests have been made of the cyclic heating characteristics of an external heater mounted on a hollow-steel propeller blade. The results indicate that the commonly employed cyclic time of 20 seconds "heat on" and 60 seconds "heat-off" is inefficient, and that power savings of 60 percent can be realized by increasing the heating intensity and decreasing the "heat-on" time to 5 seconds.

AIRCRAFT FIRE PREVENTION

The investigation of the sources of ignition and methods of fire prevention in the crash tests of full-scale airplanes which is being carried out by the NACA Lewis Flight Propulsion Laboratory on reciprocating engine aircraft is resulting in substantial knowledge of practical avenues of combating the fire problem.

The ignition of engine lubricating oils is one of the aircraft fire problems being investigated under research contract. Technical Note 2549, which covers an initial study of this problem at the University of Cincinnati, presents spontaneous ignition temperatures for a large number of organic compounds, and correlates structure with ease of ignition. The effects of a number of additives and several metal surfaces on the ignition temperatures were determined for representative compounds.

AIRCRAFT NOISE

Survey of the Aircraft Noise Problem

A survey has been completed which provides background information on the various phases of aircraft noise with special reference to the physical aspects of the problem (Technical Note 2701). The effects of noise are discussed under the following headings: (1) annoyance; (2) effect on work output and efficiency; (3) physical pain due to intense noise; and (4) effects on aircraft structural fatigue. The physical characteristics of noise are also reviewed including frequency spectrums, directional characteristics, and intensity levels for various types of power plants. In addition, means of protection from noise is discussed including exhaust muffling, spatial isolation, sound proofing, and personnel protection.

Experimental Studies of Steady Flow Jet Noise

Some experimental studies have been completed utilizing subsonic model jets in still air which have been shown to be closely related to the noise generated from a turbojet engine (Technical Note 2757). The effects of such parameters as jet velocity, density, turbulence level, and jet size were investigated and an empirical relation has been evolved which will allow extrapolation of available jet noise data to other operating conditions. It was found that the noise intensity greatly increased with increasing exit velocity and turbulence level. This intensity increase was not as great with increases in jet size and exit gas density. It was shown that in all cases, the highest level of noise existed near the jet boundary.

Experimental Measurements of Noise Associated with Intermittent Jets

Many applications of pulsejet engines appear to be attractive because of their simplicity of operation and the large thrust-weight ratio characteristic. However, the intense noise associated with their operation is a serious disadvantage and therefore sound measurements have been made to determine the characteristics of this noise (Technical Note 2756). Intensity and frequency spectrums of a pulsejet and a subsonic ram-jet were measured and compared with those of a steady flow turbo-jet with rough burning. The pulsejet was found to produce a discrete-frequency spectrum having a single predominant component corresponding to the firing frequency of the engine. The subsonic ram-jet and the turbojet also produced discrete-frequency spectrums but contrasted with the pulsejet in that their spectrums contained several harmonic components of magnitude comparable to that of the fundamental.

RESEARCH PUBLICATIONS

TECHNICAL REPORTS [1]

No.

1003. Correlation of Physical Properties with Molecular Structure for Some Dicyclic Hydrocarbons Having High Thermal-Energy Release per Unit Volume. By P. H. Wise, K. T. Serijan, and I. A. Goodman.

1004. A Lift-Cancellation Technique in Linearized Supersonic-Wing Theory. By Harold Mirels.

1006. Analysis of Thrust Augmentation of Turbojet Engines by Water Injection at Compressor Inlet Including Charts for Calculating Compression Processes with Water Injection. By E. Clinton Wilcox and Arthur M. Trout.

1007. Horizontal Tail Loads in Maneuvering Flight. By Henry A. Pearson, William A. McGowan, and James J. Donegan.

1008. A Small-Deflection Theory for Curved Sandwich Plates. By Manuel Stein and J. Mayers.

1009. Investigation of Fretting by Microscopic Observation. By Douglas Godfrey.

1010. A Recurrence Matrix Solution for the Dynamic Response of Aircraft in Gusts. By John C. Houbolt.

1011. Dynamics of a Turbojet Engine Considered as a Quasi-Static System. By Edward W. Otto and Burt L. Taylor, III.

1012. Investigation of the NACA 4-(5)(08)-03 and NACA 4-(10)(08)-03 Two-Blade Propellers at Forward Mach Numbers to 0.725 to Determine the Effects of Camber and Compressibility on Performance. By James B. Delano.

1013. Effects of Wing Flexibility and Variable Air Lift Upon Wing Bending Moments During Landing Impacts of a Small Seaplane. By Kenneth F. Merten and Edgar B. Beck.

1014. Study of Effects of Sweep on the Flutter of Cantilever Wings. By J. G. Barmby, H. J. Cunningham, and I. E. Garrick.

1015. Analysis of Turbulent Free-Convection Boundary Layer on Flat Plate. By E. R. G. Eckert and Thomas W. Jackson.

1016. Effect of Tunnel Configuration and Testing Technique on Cascade Performance. By John R. Erwin and James C. Emery.

1017. Investigation of Frequency-Response Characteristics of Engine Speed for a Typical Turbine-Propeller Engine. By Burt L. Taylor, III, and Frank L. Oppenheimer.

1018. A Theoretical Analysis of the Effect of Time Lag in an Automatic Stabilization System on the Lateral Oscillatory Stability of an Airplane. By Leonard Sternfield and Ordway B. Gates, Jr.

1019. Relation Between Inflammables and Ignition Sources in Aircraft Environments. By Wilfred E. Scull.

1020. Measurements of Average Heat-Transfer and Friction Coefficients for Subsonic Flow of Air in Smooth Tubes at High Surface and Fluid Temperatures. By Leroy V. Humble, Warren H. Lowdermilk, and Leland G. Desmon.

No.

1021. Analysis of Plane-Plastic-Stress Problems with Axial Symmetry in Strain-Hardening Range. By M. H. Lee Wu.

1022. Temperature Distribution in Internally Heated Walls of Heat Exchangers Composed of Noncircular Flow Passages. By E. R. G. Eckert and George M. Low.

1023. Diffusion of Chromium in Alpha Cobalt-Chromium Solid Solutions. By John W. Weeton.

1024. Calculation of the Lateral Control of Swept and Unswept Flexible Wings of Arbitrary Stiffness. By Franklin W. Diederich.

1025. Experimental and Theoretical Studies of Area Suction for the Control of the Laminar Boundary Layer of an NACA 64A010 Airfoil. By Albert L. Braslow, Dale L. Burrows, Neal Tetervin, and Fioravante Visconti.

1026. NACA Investigation of Fuel Performance in Piston-Type Engines. By Henry C. Barnett.

1027. Buckling of Thin-Walled Cylinder Under Axial Compression and Internal Pressure. By Hsu Lo, Harold Crate, and Edward B. Schwartz.

1028. Effect of Aspect Ratio on the Air Forces and Moments of Harmonically Oscillating Thin Rectangular Wings in Supersonic Potential Flow. By Charles E. Watkins.

1029. Compressive Strength of Flanges. By Elbridge Z. Stowell.

1030. Investigation of Separation of the Turbulent Boundary Layer. By G. B. Schubauer and P. S. Klebanoff.

1031. A Study of the Use of Experimental Stability Derivatives in the Calculation of the Lateral Disturbed Motions of a Swept-Wing Airplane and Comparison with Flight Results. By John D. Bird and Byron M. Jaquet.

1032. A Comparison of Theory and Experiment for High-Speed Free-Molecule Flow. By Jackson R. Stalder, Glen Goodwin, and Marcus O. Creager.

1033. Comparison Between Theory and Experiment for Wings at Supersonic Speeds. By Walter G. Vincenti.

1034. Investigation of Spoiler Ailerons for Use as Speed Brakes or Glide-Path Controls on Two NACA 65-Series Wings Equipped with Full-Span Slotted Flaps. By Jack Fischel and James M. Watson.

1035. Analysis of Means of Improving the Uncontrolled Lateral Motions of Personal Airplanes. By Marion O. McKinney, Jr.

1036. Experimental Investigation of the Effects of Viscosity on the Drag and Base Pressure of Bodies of Revolution at a Mach Number of 1.5. By Dean R. Chapman and Edward W. Perkins.

1037. General Method and Thermodynamic Tables for Computation of Equilibrium Composition and Temperature of Chemical Reactions. By Vearl N. Huff, Sanford Gordon, and Virginia E. Morrell.

1038. Wind-Tunnel Investigation of Air Inlet and Outlet Openings on a Streamline Body. By John V. Becker.

1039. On the Particular Integrals of the Prandtl-Busemann Iteration Equations for the Flow of a Compressible Fluid. By Carl Kaplan.

1040. Spectra and Diffusion in a Round Turbulent Jet. By Stanley Corrsin and Mahinder S. Uberoi.

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[1] The missing numbers in the series of Technical Reports were released before or after the period covered by this report.

No.

1041. Equations and Charts for the Rapid Estimation of Hinge-Moment and Effectiveness Parameters for Trailing-Edge Controls Having Leading and Trailing Edges Swept Ahead of the Mach Lines. By Kennith L. Goin.

1042. Some Effects of Nonlinear Variation in the Directional-Stability and Damping-In-Yawing Derivatives on the Lateral Stability of an Airplane. By Leonard Sternfield.

1043. A Numerical Method for the Stress Analysis of Stiffened-Shell Structures under Nonuniform Temperature Distributions. By Richard R. Heldenfels.

1044. The Method of Characteristics for the Determination of Supersonic Flow over Bodies of Revolution at Small Angles of Attack. By Antonio Ferri.

1045. Supersonic Flow Around Circular Cones at Angles of Attack. By Antonio Ferri.

1046. A General Integral Form of the Boundary-Layer Equation for Incompressible Flow with an Application to the Calculation of the Separation Point of Turbulent Boundary Layers. By Neal Tetervin and Chia Chiao Lin.

1047. The Stability of the Compression Cover of Box Beams Stiffened by Posts. By Paul Seide and Paul F. Barrett.

1048. A Study of Effects of Viscosity on Flow over Slender Inclined Bodies of Revolution. By H. Julian Allen and Edward W. Perkins.

1049. Experimental Investigation of the Effect of Vertical-Tail Size and Length and of Fuselage Shape and Length on the Static Lateral Stability Characteristics of a Model with 45° Sweptback Wing and Tail Surfaces. By M. J. Queijo and Walter D. Wolhart.

1050. Formulas for the Supersonic Loading, Lift and Drag of Flat Swept-Back Wings with Leading Edges behind the Mach Lines. By Doris Cohen.

1051. An Analysis of Base Pressure at Supersonic Velocities and Comparison with Experiment. By Dean R. Chapman.

1052. A Summary of Lateral-Stability Derivatives Calculated for Wing Plan Forms in Supersonic Flow. By Arthur L. Jones and Alberta Alksne.

1053. Investigation of Turbulent Flow in a Two-Dimensional Channel. By John Laufer.

1054. Integrals and Integral Equations in Linearized Wing Theory. By Harvard Lomax, Max. A. Heaslet, and Franklyn B. Fuller.

1055. Comparison of Theoretical and Experimental Heat-Transfer Characteristics of Bodies of Revolution at Supersonic Speeds. By Richard Scherrer.

1056. Theoretical Antisymmetric Span Loading for Wings of Arbitrary Plan Form at Subsonic Speeds. By John DeYoung.

1057. Analysis of the Effects of Boundary-Layer Control on the Take-Off and Power-Off Landing Performance Characteristics of a Liaison Type of Airplane. By Elmer A. Horton, Laurence K. Loftin, Jr., Stanley F. Racisz, and John H. Quinn, Jr.

1058. Influence of Chemical Composition on Rupture Properties at 1200° F. of Forged Chromium-Cobalt-Nickel-Iron Base Alloys in Solution-Treated and Aged Condition. By E. E. Reynolds, J. W. Freeman, and A. E. White.

TECHNICAL NOTES [1]

2323. Theoretical Investigation of Submerged Inlets at Low Speeds. By Alvin H. Sacks and John R. Spreiter.

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[1] The missing numbers in the series of Technical Notes were released before or after the period covered by this report.

No.

2368. Vaporization Rates and Heat-Transfer Coefficients for Pure Liquid Drops. By Robert D. Ingebo.

2391. Further Comparisons of Theoretical and Experimental Lift and Pressure Distributions on Airfoils in Cascade at Low-Subsonic Speed. By S. Katzoff and Margery E. Hannah.

2392. Charts Giving Critical Compressive Stress of Continuous Flat Sheet Divided into Parallelogram-Shaped Panels. By Roger A. Anderson.

2394. Effects of Design Details on the Fatigue Strength of 355-T6 Sand-Cast Aluminum Alloy. By M. Holt and I. D. Eaton.

2395. Bench-Test Investigation of the Transient-Response Characteristics of Several Simulated Airplanes Incorporating an Autopilot Sensitive to Yawing Accelerations. By Donald A. Howard.

2396. Single-Degree-of-Freedom-Flutter Calculations for a Wing in Subsonic Potential Flow and Comparison with an Experiment. By Harry L. Runyan.

2400. Evaluation of the Reduced-Mass Method of Representing Wing-Lift Effects in Free-Fall Drop Tests of Landing Gears. By Benjamin Milwitzky and Dean O. Lindquist.

2401. Temperature Distribution in Internally Heated Walls of Heat Exchangers with Noncircular Flow Passages Using Coolants with Very Low Prandtl Number. By E. R. G. Eckert and George M. Low.

2404. An Analytical Investigation of Effect of High-Lift Flaps on Take-Off of Light Airplanes. By Fred E. Weick, L. E. Flanagan, Jr., and H. H. Cherry.

2406. Application of X-Ray Absorption to Measurement of Small Air-Density Gradients. By Ruth N. Weltmann, Steven Fairweather, and Daryl Papke.

2411. Method of Determining Initial Tangents of Contours of Flow Variables Behind a Curved, Axially Symmetric Shock Wave. By George P. Wood and Paul B. Gooderum.

2412. Theoretical Force and Moments due to Sideslip of a Number of Vertical Tail Configurations at Supersonic Speeds. By John C. Martin and Frank S. Malvestuto, Jr.

2415. Experimental Study of an Angle-of-Attack Vane Mounted Ahead of the Nose of an Airplane for use as a Sensing Device for an Acceleration Alleviator. By Christopher C. Kraft, Jr., and Arthur Assadourian.

2417. Preliminary Study of Stability of Flow from Two Ducts Discharging Into a Common Duct. By Albert I. Bellin, D. Richard Messina, and Paul B. Richards.

2419. Correlation of Physical Properties with Molecular Structure for Dicyclic Hydrocarbons. II—2-Alkylbiphenyl and the Two Isomeric 2-Alkylbicyclohexyl Series. By Irving A. Goodman and Paul H. Wise.

2420. Investigation of 75-Millimeter-Bore Cylindrical-Roller Bearings at High Speeds. III—Lubrication and Cooling Studies—Oil Inlet Distribution, Oil Inlet Temperature, and Generalized Single-Oil-Jet Cooling-Correlation Analysis. By E. Fred Macks and Zolton N. Nemeth.

2421. A Rapid Approximate Method for Determining Velocity Distribution on Impeller Blades of Centrifugal Compressors. By John D. Stanitz and Vasily D. Prian.

2422. Study of Chromium-Frit-Type Coatings for High-Temperature Protection of Molybdenum. By D. G. Moore, L. H. Bolz, J. W. Pitts, and W. N. Harrison.

2426. An Investigation of Aircraft Heaters. XXXIV—Experimental Determination of Thermal and Hydrodynamical Behavior of Air Flowing Between a Flat and a Wave-Shaped Plate. By L. M. K. Boelter, V. D. Sanders, G. Young, M. Morgan, and E. H. Morrin.

No.

2427. An Investigation of Aircraft Heaters. XXXV—Thermo-couple Conduction Error Observed in Measuring Surface Temperatures. By L. M. K. Boelter and R. W. Lockhart.

2428. An Investigation of Aircraft Heaters. XXXVI—Preliminary Investigation of a Combustion-Type Aircraft Heater. By L. M. K. Boelter, W. R. Elswick, V. D. Sanders, and M. W. Rubesin.

2429. Study of Vortex Shedding as Related to Self-Excited Torsional Oscillations of an Airfoil. By Raymond L. Chuan and Richard J. Magnus.

2430. Synthesis, Purification, and Physical Properties of Hydrocarbons of the Naphthalene Series I-1-Methylnapthalene, 1-Ethylnaphthalene, 1-Butylnaphthalene, and 1-Isobutyl-naphthalene. By Harold F. Hipsher and Paul H. Wise.

2432. Transformations of the Hodograph Flow Equation and the Introduction of Two Generalized Potential Functions. By Luigi Crocco.

2433. A Critical Review of Notch Sensitivity in Stress-Rupture Tests. By W. F. Brown, Jr., and George Sachs.

2434. A Biharmonic Relaxation Method for Calculating Thermal Stress in Cooled Irregular Cylinders. By Arthur G. Holms.

2436. Heat Delivery in a Compressible Flow and Applications to Hot-Wire Anemometry. By Chan-Mou Tchen.

2437. Some Measurements of the Effect of Gaseous Imperfections on the Critical Pressure Ratio in Air and the Speed of Sound in Nitrogen. By Coleman duP. Donaldson and Jim J. Jones.

2439. A Theory of Conductivity of Cold-Worked Copper. By Rolf Landauer.

2440. Wind-Tunnel Investigation and Analysis of the Effects of End Plates on the Aerodynamic Characteristics of an Unswept Wing. By Donald R. Riley.

2441. Optical Methods Involving Light Scattering for Measuring Size and Concentration of Condensation Particles in Supercooled Hypersonic Flow. By Enoch J. Durbin.

2442. A Photoelastic Investigation of Stress Concentrations Due to Small Fillets and Grooves in Tension. By M. M. Frocht.

2445. Wind-Tunnel Tests at Low Speed of Swept and Yawed Wings Having Various Plan Forms. By Paul E. Purser and M. Leroy Spearman.

2446. Width of Debye-Scherrer Lines for Finite Spectral Width of Primary Beam. By Hans Ekstein.

2447. Statistical Fluctuation of Intensity in Debye-Scherrer Lines Due to Random Orientation of Crystal Grains. By Hans Ekstein.

2448. X-Ray Diffraction by Bent Crystal Lamellae. By Hans Ekstein.

2449. Investigation of Influence of Chemical Composition on Forged Modified Low-Carbon N-155 Alloys in Solution-Treated and Aged Condition as Related to Rupture Properties at 1200° F. By E. E. Reynolds, J. W. Freeman, and A. E. White.

2450. Method of Matching Components and Predicting Performance of a Turbine-Propeller Engine. By Alois T. Sutor and Morris A. Zipkin.

2451. Mathematical Improvement of Method for Computing Poisson Integrals Involved in Determination of Velocity Distribution on Airfoils. By I. Flügge-Lotz.

2452. Flexural Fatigue Strengths of Riveted Box Beams—Alclad 14S-T6, Alclad 75S-T6, and Various Tempers of Alclad 24S. By L. D. Eaton and Marshall Holt.

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2453. An Experimental Study of Water-Pressure Distributions During Landings and Planing of a Heavily Loaded Rectangular Flat-Plate Model. By Robert F. Smiley.

2454. Jet-Boundary Corrections for Complete and Semispan Swept Wings in Closed Circular Wind Tunnels. By James C. Sivells and Rachel M. Salmi.

2455. A Method of Designing Turbomachine Blades with a Desirable Thickness Distribution for Compressible Flow along an Arbitrary Stream Filament of Revolution. By Chung-Hua Wu and Curtis A. Brown.

2456. Analytical Method for Determining Performance of Turbo-jet-Engine Tail-Pipe Heat Exchangers. By Michael Behun and Harrison C. Chandler, Jr.

2457. Air Forces and Moments on Triangular and Related Wings with Subsonic Leading Edges Oscillating in Supersonic Potential Flow. By Charles E. Watkins.

2458. An Instrument Employing a Coronal Discharge for the Determination of Droplet-Size Distribution in Clouds. By Rinaldo J. Brun, Joseph Levine, and Kenneth S. Kleinknecht.

2459. Some Effects of Varying the Damping in Pitch and Roll on the Flying Qualities of a Small Single-Rotor Helicopter. By John P. Reeder and James B. Whitten.

2460. Formation of Sulfide Films on Steel and Effect of Such Films on Static Friction. By Erva C. Levine and Marshall B. Peterson.

2461. Analysis of Pure-Bending Flutter of a Cantilever Swept Wing and Its Relation to Bending-Torsion Flutter. By H. J. Cunningham.

2462. Influence of Refraction on the Applicability of the Zehnder-Mach Interferometer to Studies of Cooled Boundary Layers. By Martin R. Kinsler.

2463. Experimental Investigation of the Pressure Distribution about a Yawed Circular Cylinder in the Critical Reynolds Number Range. By William J. Bursnall and Laurence K. Loftin, Jr.

2464. Two Axial-Symmetry Solutions for Incompressible Flow Through a Centrifugal Compressor with and without Inducer Vanes. By Gaylord O. Ellis, John D. Stanitz, and Leonard J. Sheldrake.

2465. Experimental Aerodynamic Derivatives of a Sinusoidally Oscillating Airfoil in Two-Dimensional Flow. By Robert L. Halfman.

2466. A General Correlation of Temperature Profiles Downstream of a Heated-Air Jet Directed Perpendicularly to an Air Stream. By Edmund E. Callaghan and Robert S. Ruggeri.

2467. The Aerodynamic Behavior of a Harmonically Oscillating Finite Sweptback Wing in Supersonic Flow. By Chieh-Chien Chang.

2468. Investigation at Low Speed of 45° and 60° Sweptback, Tapered, Low-Drag Wings Equipped with Various Types of Full-Span, Trailing-Edge Flaps. By John J. Harper.

2469. Rupture Properties of Low-Carbon N-155 Type Alloys Made with a Columbium-Tantalum Ferro-Alloy. By J. W. Freeman, E. E. Reynolds, and A. E. White.

2470. Effect of an Autopilot Sensitive to Yawing Velocity on the Lateral Stability of a Typical High-Speed Airplane. By Ordway B. Gates, Jr., and Leonard Sternfield.

2471. Unsteady Laminar Boundary-Layer Flow. By Franklin K. Moore.

2472. Fundamental Effects of Cold-Working on Creep Properties of Low-Carbon N-155 Alloy. By D. N. Frey, J. W. Freeman, and A. E. White.

No.

2744. Practical Calculation of Second-Order Supersonic Flow Past Nonlifting Bodies of Revolution. By Milton D. Van Dyke.

2748. On Transonic Flow Past a Wave-Shaped Wall. By Carl Kaplan.

2749. Analysis of Flow in a Subsonic Mixed-Flow Impeller. By Chung-Hua Wu, Curtis A. Brown, and Eleanor L. Costilow.

2750. Matrix and Relaxation Solutions that Determine Subsonic Through Flow in an Axial-Flow Gas Turbine. By Chung-Hua Wu.

2752. A Study of the Stability of the Laminar Boundary-Layer as Affected by Changes in the Boundary-Layer Thickness in Regions of Pressure Gradient and Flow through the Surface. By Neal Tetervin and David A. Levine.

2754. A Method of Selecting the Thickness, Hollowness, and Size of a Supersonic Wing for Least Drag and Sufficient Bending Strength at Specified Flight Conditions. By James L. Amick.

2756. Noise from Intermittent Jet Engines and Steady-Flow Jet Engines with Rough Burning. By Leslie W. Lassiter.

2757. Experimental Studies of Noise from Subsonic Jets in Still Air. By Leslie W. Lassiter and Harvey H. Hubbard.

2758. Wear and Sliding Friction Properties of Nickel Alloys Suited for Cages of High-Temperature Rolling-Contact Bearings. I—Alloys Retaining Mechanical Properties to 600° F. By Robert L. Johnson, Max A. Swikert, and Edmond E. Bisson.

2759. Wear and Sliding Friction Properties of Nickel Alloys Suited for Cages of High-Temperature Rolling-Contact Bearings. II—Alloys Retaining Mechanical Properties above 600° F. By Robert L. Johnson, Max A. Swikert, and Edmond E. Bisson.

2760. Derivation of Stability Criterions for Box Beams with Longitudinally Stiffened Covers Connected by Posts. By Paul Seide.

2761. Instrument-Flight Results Obtained with a Combined-Signal Flight Indicator Modified for Helicopter Use. By Almer D. Crim, John P. Reeder, and James B. Whitten.

2778. Stress and Strain at Onset of Crazing of Polymethyl Methacrylate at Various Temperatures. By M. A. Sherman and B. M. Axilrod.

2779. Effects of Moderate Biaxial Stretch-Forming on Tensile and Crazing Properties of Acrylic Plastic Glazing. By B. M. Axilrod, M. A. Sherman, V. Cohen, and I. Wolock.

2782. Bending of Thin Plates with Compound Curvature. By H. G. Lew.

2795. Effects of Wing Sweep on the Upwash at the Propeller Planes of Multiengine Airplanes. By Vernon L. Rogallo.

2799. Simple Graphical Solution of Heat Transfer and Evaporation from Surface Heated to Prevent Icing. By Vernon H. Gray.

TECHNICAL MEMORANDUMS [1]

Citations to German reports in this list will use the following abbreviations where applicable:

ZWB—Zentrale für Wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (German Central Publication Office for Aeronautical Reports).

FB—Forschungsbericht (Research Report).

UM—Untersuchungen und Mitteilungen (Reports and Memoranda).

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[1] The missing numbers in the series of Technical Memorandums were released before or after the period covered by this report.

No.

1264. Calculation of the Lateral-Dynamic Stability of Aircraft. By A. Raikh. From Tsentralnogo Aero-Gidrodinamicheskogo Instituta, Trudy (CAHI Report) No. 453, 1939.

1274. Behavior of Fast Moving Flow of Compressible Gas in Cylindrical Pipe in Presence of Cooling. By G. A. Varshavsky. From Zhurnal Teknicheskoi Fiziki (U. S. S. R.), Vol. 16, No. 4, 1946, pp. 413–416.

1277. Present State of Development in Nonsteady Motion of a Lifting Surface. By P. Cicala. From L'Aerotecnica, Vol. 21, No. 9–10, September–October 1941.

1290. The Structure of Airy's Stress Function in Multiply Connected Regions. By Giusippe Grioli. From Giornale di Matematiche, Vol. 77, 1947, pp. 119–144.

1298. Approximate Method of Integration of Laminar Boundary Layer in Incompressible Fluid. By L. G. Loitsianskii. From Prikladnaya Matematika i Mekhanika (U. S. S. R.) Vol. 13, No. 5, Oct. 1949, pp. 513–525.

1300. Wind-Tunnel Corrections at High Subsonic Speeds Particularly for an Enclosed Circular Tunnel. By B. H. Göthert. From Deutsche Versuchsanstalt für Luftfahrt, E. V., Institut für Aerodynamik, Berlin-Adlershof, FB 1216, May, 1940.

1301. The Flow of Gases in Narrow Channels. By R. E. H. Rasmussen. From Annalen der Physik, Vol. 29, No. 8, August 1937, pp. 665–697.

1302. Stability of the Cylindrical Shell of Variable Curvature. By K. Marguerre. From ZWB, FB 1671, Sept. 16, 1942.

1303. Resistance of Cascade of Airfoils in Gas Stream at Subsonic Velocity. By L. G. Loitsianskii. From Prikladnaia Matematika i Mekhanika, Vol. 13, No. 2, 1949.

1304. Generalization of Joukowski Formula to an Airfoil of a Cascade in Compressible Gas Stream with Subsonic Velocities. By L. G. Loitsianskii. From Prikladnaia Matematika i Mekhanika, Vol. 13, No. 2, 1949, pp. 209–216.

1306. Three Papers from Conference on "Wing and Tail-Surface Oscillations"—March 6–8, 1941, Munich. I. Remarks Concerning Aerodynamically Balanced Control Surfaces. By H. Söhngen. II. Aerodynamically Equivalent Systems for Various Forms of Control Surfaces within the Scope of the Two-Dimensional Wing Theory. By L. Schwarz. III. Comparative Calculations Concerning Aerodynamic Balance of Control Surfaces. By F. Dietze. From Lilienthal-Gesellschaft für Luftfahrtforschung, Bericht 135, pp. 61–74.

1307. Lateral Control by Spoilers at the DVL. By M. Kramer, Th. Zobel, and C. G. Esche. I. Systematic Wind-Tunnel Tests Concerning the Problem of Lateral Control by Spoilers Permeable to Air. By M. Kramer and Th. Zobel. II. Contribution to the Lateral Control by Spoilers at the DVL. By M. Kramer. III. Flight Tests in the Lateral Controls by Spoilers on the Airplane Model Fieseler FI 156. By C. G. Esche. From ZWB, FB 964, May 24, July 13, 1938, May 13, 1939.

1308. On Motion of Fluid in Boundary Layer near Line of Intersection of Two Planes. By L. G. Loitsianskii and V. P. Bolshakov. From CAHI, Report 279, 1936, pp. 3–18.

1309. On the Theory of Thin and Thin-Walled Rods. By G. Y. Dzhanelidze. From Prikladnaya Matematika i Mekhanika, Vol. 13, Nov.–Dec. 1949, pp. 597–608.

1311. Contributions to the Theory of the Spreading of a Free Jet Issuing from a Nozzle. By W. Szablewski. From ZWB, UM 8003, Sept. 1944.

1313. On the Recording of Turbulent Longitudinal and Transverse Fluctuations. By H. Reichardt. From Zeitschrift für angewandte Mathematik und Mechanik, Vol. 18, No. 6, Dec. 1938, pp. 358–361.

No.

1314. On the Turbulent Friction Layer for Rising Pressure. By K. Wieghardt and W. Tillmann. From ZWB, UM 6617, November 20, 1944.

1315. Displacement Effect of the Laminar Boundary Layer and the Pressure Drag. By H. Görtler. From Ingenieur-Archiv, Vol. 14, 1944, pp. 286–305.

1316. Resistance of a Plate in Parallel Flow at Low Reynolds Numbers. By Zbynek Janour. From Letecký Vyzkumný Ústav, Praha, Rep. 2, 1947.

1317. A Simple Numerical Method for the Calculation of the Laminar Boundary Layer. By K. Schröder. From ZWB, FB 1741, Feb. 25, 1943.

1318. Friction and Wear. By J. Pomey. From Office National d'Etudes et de Recherches Aeronautiques Rapport Technique No. 36, 1948.

1319. Torsion and Bending of Prismatic Rods of Hollow Rectangular Section. By B. L. Abramyan. From Prikladnaya Matematika i Mekhanika, Vol. 14, No. 3, 1950, pp. 265–276.

1320. Investigations on Wings with and without Sweepback at High Subsonic Speeds. By Jakob Ackeret, Max Degen, and Nikolaus Rott. From Zeitschrift für angewandte Mathematik und Physik (ZAMP) Vol. 1, 1950, pp. 32–42.

1321. Relations between the Modulus of Elasticity of Binary Alloys and Their Structure. By Werner Köster and Walter Rauscher. From Zeitschrift für Metallkunde, Vol. 39, 1948, pp. 111–120.

1322. Theory of Thin-Walled Rods. By A. L. Goldenveizer. From Prikladnaya Matematika i Mekhanika, Vol. 13, Nov.–Dec. 1949, pp. 561–596.

1323. Influence of Static Longitudinal Stability on the Behavior of Airplanes in Gusts. By H. Hoene. From ZWB, FB 1422, Dec. 31, 1940.

1325. Concerning the Flow About Ring-Shaped Cowlings of Finite Thickness. Part I. By Dietrich Küchemann. From ZWB, FB 1236, June 13, 1940.

1326. Concerning the Flow About Ring-Shaped Cowlings, Part II—Annular Bodies of Infinite Length with Circulation for Smooth Entrance. By Dietrich Küchemann and Johanna Weber. From ZWB, FB 1236/2, Nov. 11, 1940.

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1332. Extension to the Cases of Two Dimensional and Spherically Symmetric Flows of Two Particular Solutions to the Equations of Motion Governing Unsteady Flow in a Gas. By Lorenzo Poggi. From L'Aerotecnica, Numero Speciale in Onore di Modesto Panetti, 25 November 1950.

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Part II—COMMITTEE ORGANIZATION

As established by law, the National Advisory Committee for Aeronautics consists of 17 members appointed by The President and reporting to him. The membership includes two representatives each from the Air Force, the Navy Bureau of Aeronautics, and of the Civil Aeronautics Administration, and single representatives from the Smithsonian Institution, the U. S. Weather Bureau, the National Bureau of Standards, and the Research and Development Board of the Department of Defense. The seven other members, who serve for five-year terms, are private citizens chosen from industry and the sciences. Representatives of the Government organizations serve for indefinite periods, and all members serve as such without compensation.

During the past year, the following changes in Committee membership took place:

Lieutenant General Laurence C. Craigie, Deputy Chief of Staff, Development, of the United States Air Force, was appointed by President Truman a member of the NACA December 15, 1951, to succeed Major General Gordon P. Saville, whose membership on the Committee was terminated July 31, 1951, upon his retirement from the Air Force.

Another vacancy on the Committee was filled on June 5, 1952, when The President appointed Dr. Allen V. Astin, the new Director of the National Bureau of Standards, as a member of the NACA. Dr. Astin succeeded Dr. Edward U. Condon, whose membership on the NACA was terminated September 30, 1951, concurrently with his resignation as Director of the Bureau of Standards.

Vice Admiral Mathias B. Gardner, Deputy Chief of Naval Operations (Air), was appointed a member of the NACA on May 13, 1952, succeeding Vice Admiral John H. Cassady, who had just been detached from the same Navy post and assigned to sea duty.

On September 16, 1952, The President appointed Rear Admiral Thomas S. Combs, Chief of the Bureau of Aeronautics of the Navy, as a member of the NACA Vice Rear Admiral Theodore C. Lonnquest, relieved upon his transfer from duty in Washington, where he had served as Deputy and Assistant Chief of the Bureau of Aeronautics.

On October 16, 1952, Dr. Jerome C. Hunsaker was reelected Chairman of the NACA and of the Executive Committee. At the same time, Dr. Alexander Wetmore was reelected Vice Chairman of the NACA and Dr.

Francis W. Reichelderfer was reelected Vice Chairman of the Executive Committee.

The Committee membership is as follows:

Dr. Jerome C. Hunsaker, Massachusetts Institute of Technology, Chairman

Dr. Alexander Wetmore, Smithsonian Institution. Vice Chairman

Dr. Allen V. Astin, National Bureau of Standards.

Dr. Detlev W. Bronk, The Johns Hopkins University.

Rear Admiral Thomas S. Combs, USN, Chief of the Bureau of Aeronautics.

Lieutenant General Laurence C. Craigie, USAF, Deputy Chief of Staff, Development.

Honorable Thomas W. S. Davis, Assistant Secretary of Commerce.

Dr. James H. Doolittle, Shell Oil Company.

Vice Admiral Matthias B. Gardner, USN, Deputy Chief of Naval Operations (Air).

Mr. Ronald M. Hazen, Allison Division, General Motors Corporation.

Mr. William Littlewood, American Airlines, Inc.

Honorable Donald W. Nyrop, Civil Aeronautics Board.

Major General Donald L. Putt, USAF, Vice Commander, Air Research and Development Command.

Dr. Arthur E. Raymond, Douglas Aircraft Company, Inc.

Dr. Francis W. Reichelderfer, U. S. Weather Bureau.

Honorable Walter G. Whitman, Research and Development Board.

Dr. Theodore P. Wright, Cornell University.

Assisting the Committee in its coordination of aeronautical research are four technical committees: Aerodynamics, Power Plants for Aircraft, Construction, and Operating Problems. Each of these committees is supported by from three to eight technical subcommittees. The Committee is assisted in the formulation of general policy by an Industry Consulting Committee.

In the annual reorganization of technical committees and subcommittees of the NACA for the calendar year 1952, the Special Subcommittee on the Upper Atmosphere, under the Committee on Aerodynamics, was discharged with thanks, since it was considered that such activities in the field of research on the upper atmosphere as are of special importance to the NACA may be carried on under the cognizance of the Subcommittee on Meteorological Problems.

Two new special subcommittees were established to meet the needs that have arisen: a Special Subcommittee on Power Plant Controls, appointed June 12, 1952, under the Committee on Power Plants for Aircraft; and a Special Subcommittee on Aircraft Noise, established March 4, 1952, under the Committee on Operating Problems.

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Mr. I. Irving Pinkel, NACA Lewis Flight Propulsion Laboratory.
Mr. J. S. Alford, General Electric Co.
Mr. Don O. Benson.
Mr. F. L. Boeke, North American Aviation, Inc.
Dr. Wallace E. Howell, W. E. Howell Associates.
Mr. Victor Hudson, Consolidated Vultee Aircraft Corp.
Mr. E. F. Katzenberger, Sikorsky Aircraft Division, United Aircraft Corp.
Mr. David A. North, American Airlines, Inc.
Mr. W. W. Reaser, Douglas Aircraft Co., Inc.

Mr. Boyd C. Meyers, II, Secretary

Subcommittee on Aircraft Fire Prevention

Mr. Raymond D. Kelly, United Air Lines, Inc., Chairman.
Major John V. Norton, U. S. A. F., Air Research and Development Command.
Mr. Frederick A. Wright, Wright Air Development Center.
Lt. Col. Walter R. Taliaferro, U. S. A. F., Technical Inspection and Flight Safety Research.
Mr. Arthur V. Stamm, Bureau of Aeronautics, Department of the Navy.
Mr. David L. Posner, Civil Aeronautics Administration.
Mr. Harvey L. Hansberry, Civil Aeronautics Administration.
Mr. Hugh B. Freeman, Civil Aeronautics Board.
Mr. A. C. Hutton, National Bureau of Standards.
Mr. Lewis A. Rodert, NACA Lewis Flight Propulsion Laboratory.
Mr. E. M. Barber, The Texas Co.
Mr. Allen W. Dallas, Air Transport Association of America.
Mr. Harold E. Hoben, American Airlines, Inc.
Mr. C. R. Johnson, Shell Oil Co.
Mr. Frank C. Mock, Bendix Aviation Corp.
Mr. Ivar L. Shogran, Douglas Aircraft Co., Inc.
Mr. William I. Stieglitz, Republic Aviation Corp.
Mr. Clem G. Trimbach, Cornell Aeronautical Laboratory, Inc.
Mr. R. N. Wallace, Pratt and Whitney Aircraft Division, United Aircraft Corp.

Mr. Richard S. Cesaro, Secretary

Special Subcommittee on Aircraft Noise

Mr. William Littlewood, American Airlines, Inc., Chairman.
Mr. Charles Froesch, Eastern Air Lines, Inc.
Major H. O. Parrack, U. S. A. F., Wright Air Development Center.
Comdr. M. H. Goodwin, MC U. S. N., Bureau of Medicine and Surgery.

Mr. Stephen Rolle, Civil Aeronautics Administration.
Dr. Richard K. Cook, National Bureau of Standards.
Mr. Macon C. Ellis, Jr., NACA Langley Aeronautical Laboratory.
Mr. Arthur A. Regier, NACA Langley Aeronautical Laboratory.
Mr. Newell D. Sanders, NACA Lewis Flight Propulsion Laboratory.
Dr. Richard H. Bolt, Massachusetts Institute of Technology.
Mr. Allen W. Dallas, Air Transport Association of America.
Dr. Stacy R. Guild, Johns Hopkins Hospital.
Dr. Ross A. McFarland, Harvard School of Public Health.
Mr. Karl D. Swartzel, Cornell Aeronautical Laboratory, Inc.

Dr. T. L. K. Smull, Secretary

Industry Consulting Committee

Mr. William M. Allen, Boeing Airplane Co., Chairman.
Mr. Ralph S. Damon, Trans World Airlines, Inc., Vice Chairman.
Mr. Preston R. Bassett, Sperry Gyroscope Co., Inc.
Mr. J. H. Carmichael, Capital Airlines, Inc.
Mr. L. R. Grumman, Grumman Aircraft Engineering Corp.
Mr. Roy T. Hurley, Curtiss-Wright Corp.
Mr. C. W. LaPierre, General Electric Co.
Mr. Mundy I. Peale, Republic Aviation Corp.
Mr. Dwane L. Wallace, Cessna Aircraft Co.

Dr. T. L. K. Smull, Secretary

Part III—FINANCIAL REPORT

Appropriations for the fiscal year 1952.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1952 in the Independent Offices Appropriation Act, 1952, approved August 31, 1951, and the Third Supplemental Appropriation Act, 1952, approved June 5, 1952:

Salaries and expenses_____ $50,650,000

Construction and equipment of laboratory facilities:

Funds to complete financing of the fiscal year 1949 program:

Langley Aeronautical Laboratory	$872,800	
Lewis Flight Propulsion Laboratory	550,000	
		922,800

Funds to complete financing of the fiscal year 1950 program:

Langley Aeronautical Laboratory	3,490,424	
Pilotless Aircraft Station	3,100	
Lewis Flight Propulsion Laboratory	1,500,000	
		4,993,524

Funds to continue financing of the fiscal year 1951 program:

Langley Aeronautical Laboratory	1,233,676	
Ames Aeronautical Laboratory	4,550,000	
		5,783,676

Funds to completely finance the fiscal year 1952 program:

Langley Aeronautical Laboratory	647,000	
Pilotless Aircraft Station	173,000	
High-Speed Flight Station	4,000,000	
Ames Aeronautical Laboratory	1,480,000	
Lewis Flight Propulsion Laboratory	350,000	
		6,650,000

Total appropriated funds, fiscal year 1952_____ $69,000,000

Obligations incurred against the fiscal year 1952 appropriated funds are listed below, together with the unobligated balances remaining on June 30, 1952. The figures shown for salaries and expenses include the costs for personal services, travel, transportation, communication, utility services, printing and reproduction, contractual services, supplies, and equipment.

Salaries and expenses:

NACA Headquarters	$1,262,954
Langley Aeronautical Laboratory	19,655,769
Pilotless Aircraft Station	777,545
High-Speed Flight Station	1,208,163
Ames Aeronautical Laboratory	8,262,767
Western Coordination Office	16,280
Lewis Flight Propulsion Laboratory	18,344,196

Salaries and expenses—Continued

Wright-Patterson Coordination Office	$11,384
Research contracts—educational institutions	763,051
Services performed by National Bureau of Standards and Forest Products Laboratory	234,500
Unobligated balance	113,391
	$50,650,000

Construction and equipment of laboratory facilities:

Funds to complete financing of the fiscal year 1949 program:

Langley Aeronautical Laboratory	$370,179	
Lewis Flight Propulsion Laboratory	547,186	
Unobligated balance	5,435	
		$922,800

Funds to complete financing of the fiscal year 1950 program:

Langley Aeronautical Laboratory	3,442,481	
Pilotless Aircraft Station	3,042	
Lewis Flight Propulsion Laboratory	1,480,727	
Unobligated balance	67,274	
		4,993,524

Funds to continue financing of the fiscal year 1951 program:

Langley Aeronautical Laboratory	1,226,378	
Ames Aeronautical Laboratory	4,546,780	
Unobligated balance	10,518	
		5,783,676

Funds to completely finance the fiscal year 1952 program:

Langley Aeronautical Laboratory	94,880	
Pilotless Aircraft Station	3,800	
High-Speed Flight Station	161,000	
Ames Aeronautical Laboratory	211,633	
Lewis Flight Propulsion Laboratory	150,208	
Unobligated balance	[1] 6,028,479	
		6,650,000

Total appropriated funds, fiscal year 1952_____ $69,000,000

Appropriation for the Unitary Wind Tunnel Plan Act.—Funds in the amount of $75,000,000 were appropriated in the Deficiency Appropriation Act, 1950, approved June 29, 1950, for the construction of wind tunnels authorized in the Unitary Wind Tun-

[1] This unobligated balance remains available for obligation until expended.

nel Plan Act of 1949 (Public Law 415, 81st Cong., approved October 27, 1949). These funds are available until expended. Allotments and obligations as of June 30, 1952, are as follows:

	Allotments	Obligations as of June 30, 1952
Langley Aeronautical Laboratory	$15,067,000	$13,166,492
Ames Aeronautical Laboratory	27,077,000	22,176,994
Lewis Flight Propulsion Laboratory	32,856,000	15,087,928
Total	$75,000,000	$50,431,414

Appropriations for the fiscal year 1953.—The major allotments of the funds appropriated for the Committee for the fiscal year 1953 in the Independent Offices Appropriation Act, 1953, approved July 5, 1952, are as follows:

Salaries and expenses_____ $48,586,100

Construction and equipment of laboratory facilities:

Funds to continue financing of the fiscal year 1951 program:

Langley Aeronautical Laboratory	$516,324	
Ames Aeronautical Laboratory	483,676	
		$1,000,000

Funds to completely finance the fiscal year 1953 program:

Langley Aeronautical Laboratory	11,115,000	
Lewis Flight Propulsion Laboratory	5,585,000	
		16,700,000

Total appropriated funds, fiscal year 1953_____ $66,286,100